Measuring Open Bottom Production with Fast MAPS Detector at sPHENIX

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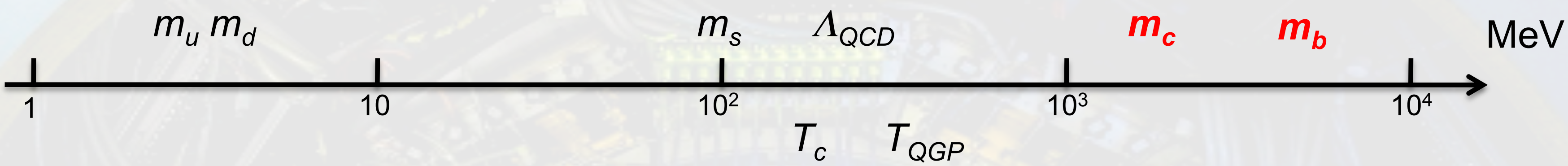
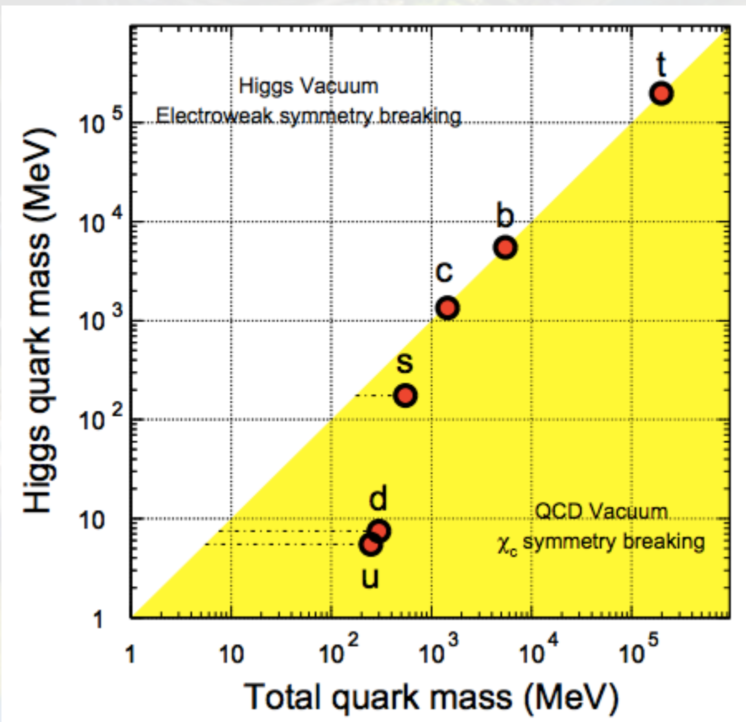
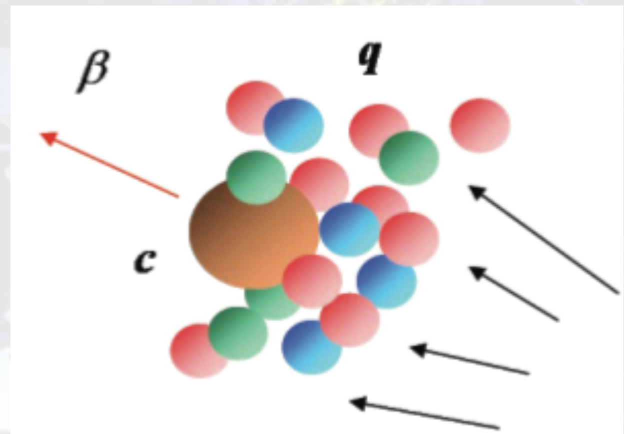
- Heavy flavor physics in HIC
- STAR Heavy Flavor Tracker
- Open bottom production
    - estimation for sPHENIX performance
- To-do and Summary

Uniqueness of Heavy Quarks in QCD





Zhu et al., PLB 647(2007)366



When $M_{HQ} \gg T$, $M_{HQ} \gg gT$

"Brownian" motion
→ Langevin simu.

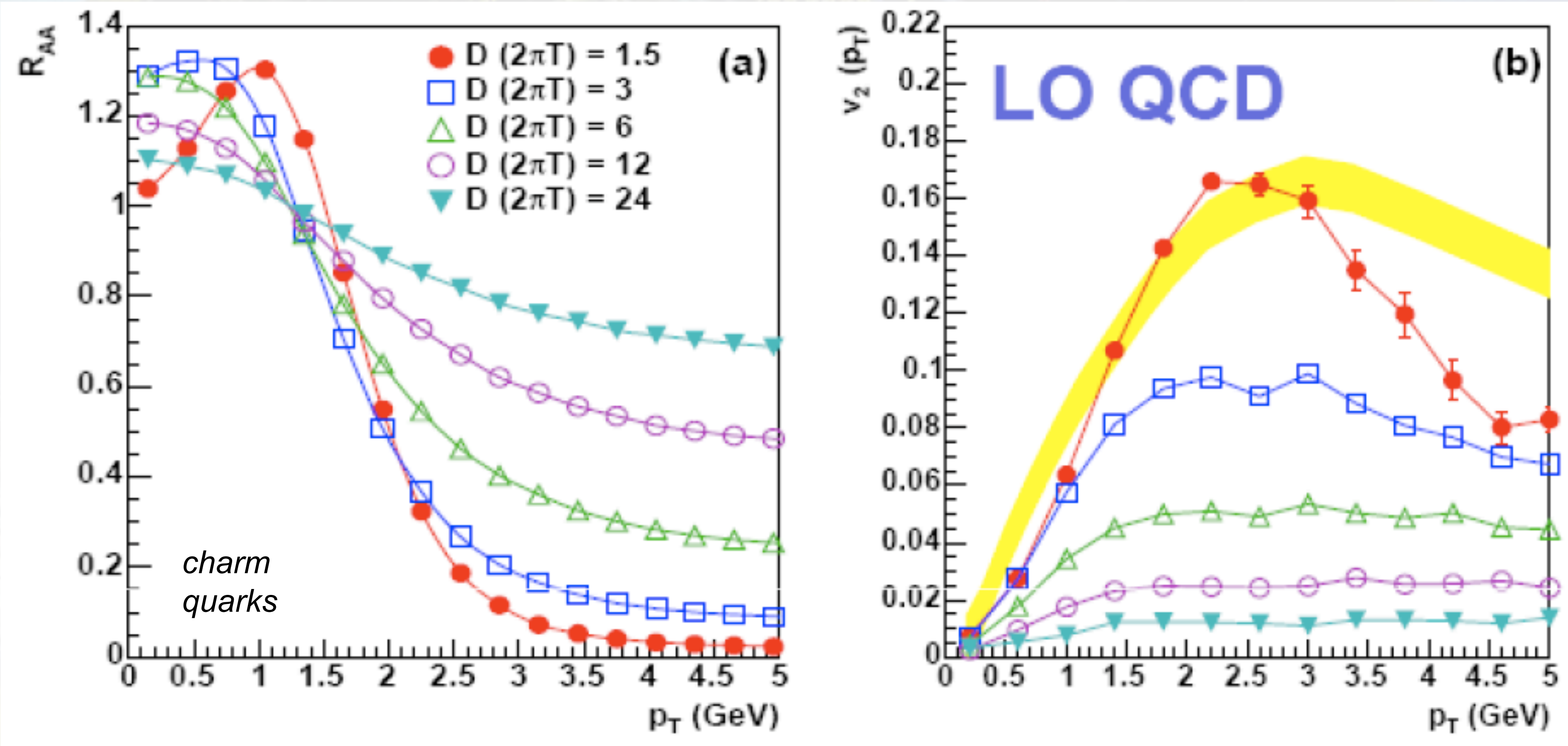
$$\frac{dp^i}{dt} = -\eta_D p^i + \xi^i(t),$$

drag

fluctuations

Diffusion coefficient D_{HQ}

HQ: Sensitive to Medium Transport Parameter



Moore & Teaney, PRC 71 (2005) 064904

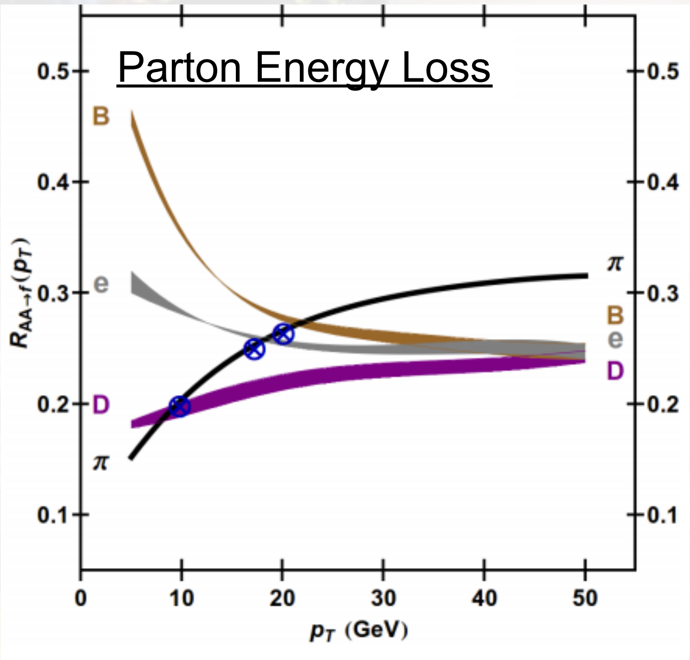
Heavy Quarks to Study sQGP Properties

A) To establish a consistent framework

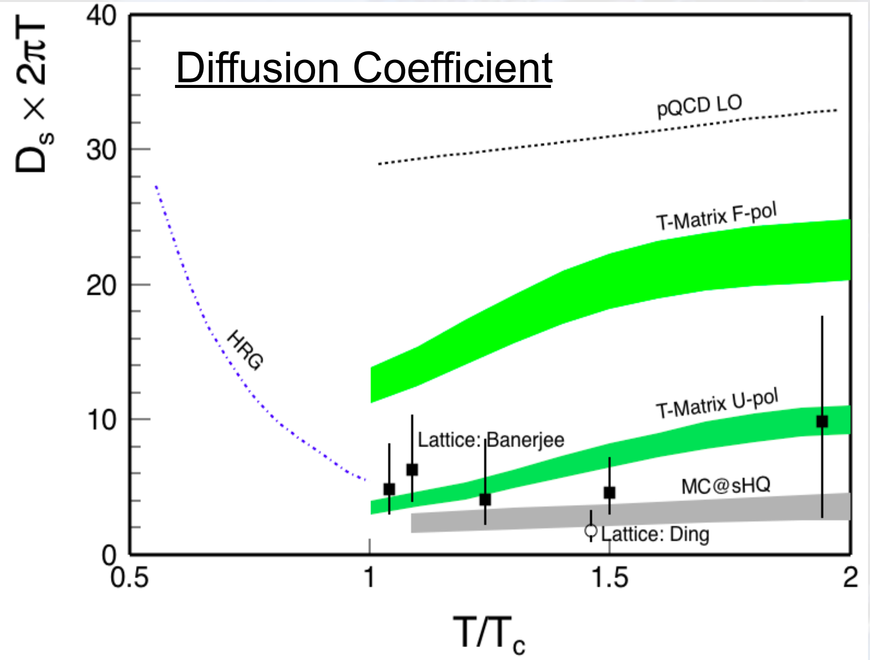
- to describe the strongly coupled medium and interactions

B) To measure intrinsic transport properties of sQGP medium: ***D_{HQ}, η/s etc.***

Other Ingredients: p+p reference - pQCD, Cold Nuclear Matter (CNM) effects …



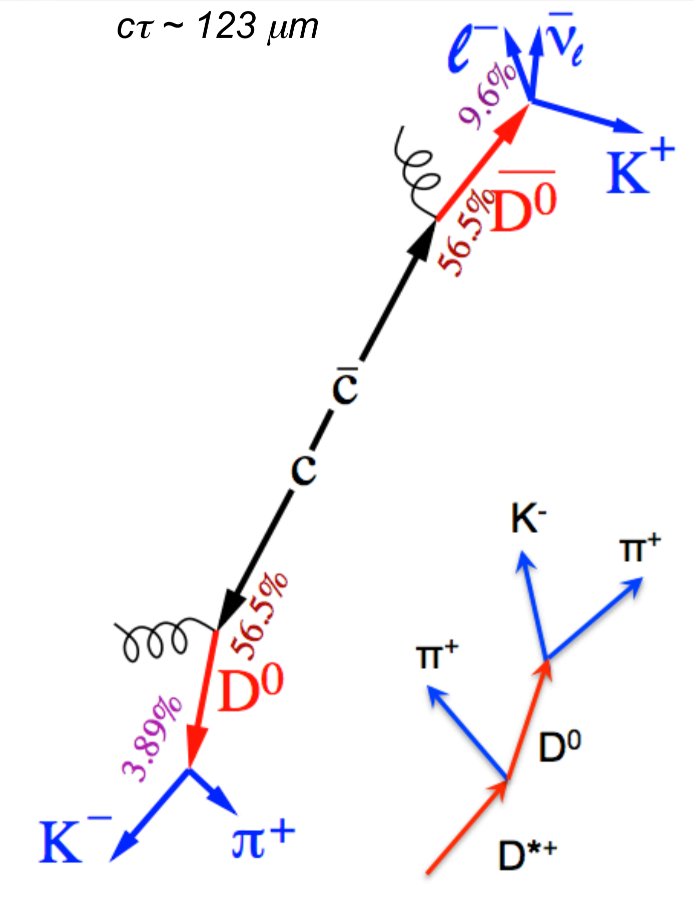
Buzzatti et al., PRL 108 (2012) 022301



arXiv: 1502.02730, 1506.03981

Experimental Challenges

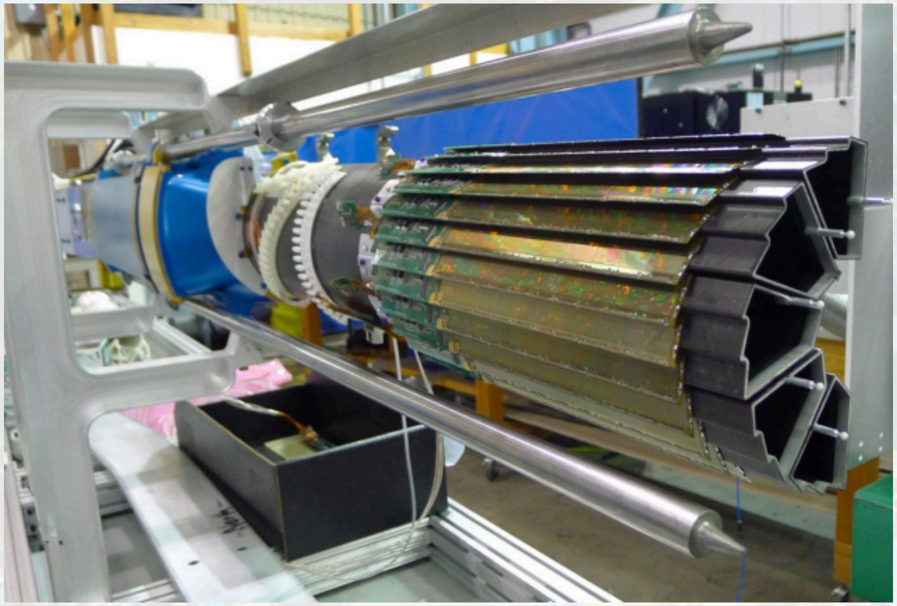
Hadron	Abundance	$c\tau$ (μm)
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

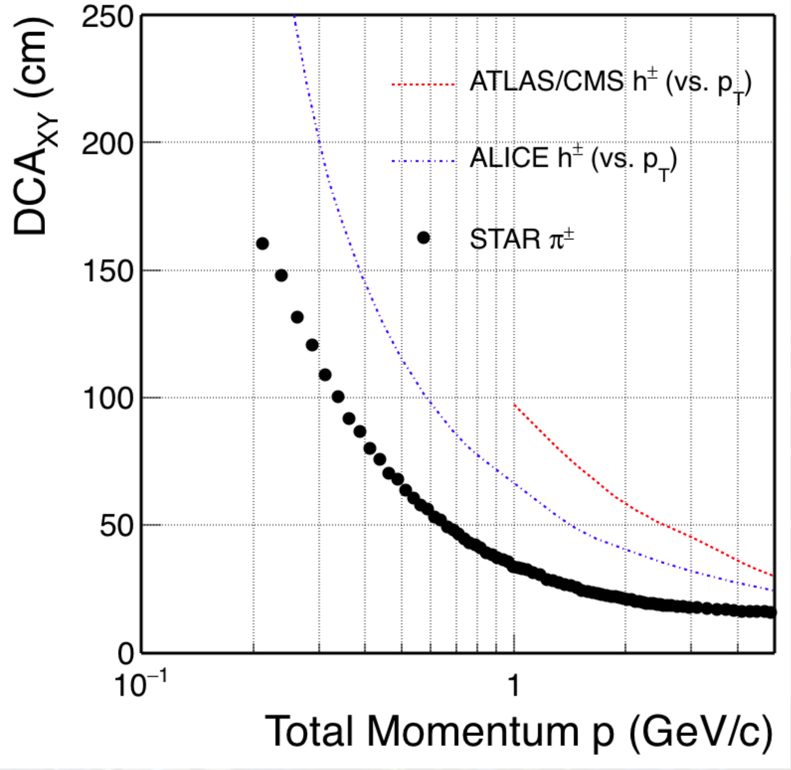


Courtesy: D. Tlusty

Precision vertex detector to reduce combinatorial background is critical for precise measurement

STAR Heavy Flavor Tracker





STAR HFT/PXL – first application of MAPS pixel detector at a collider

- Aim for precision measurements of charmed hadron production in HIC
- PXL detector designed, developed and constructed (including mechanics) at LBNL
- First layer thickness: 0.4%X_0
- Pitch size 20.7x20.7μm

$\Big\}$ critical for ultimate pointing resolution in wide p

- Integration time: 186 μs (see next page)

Hit Density on STAR PXL at RHIC Environment

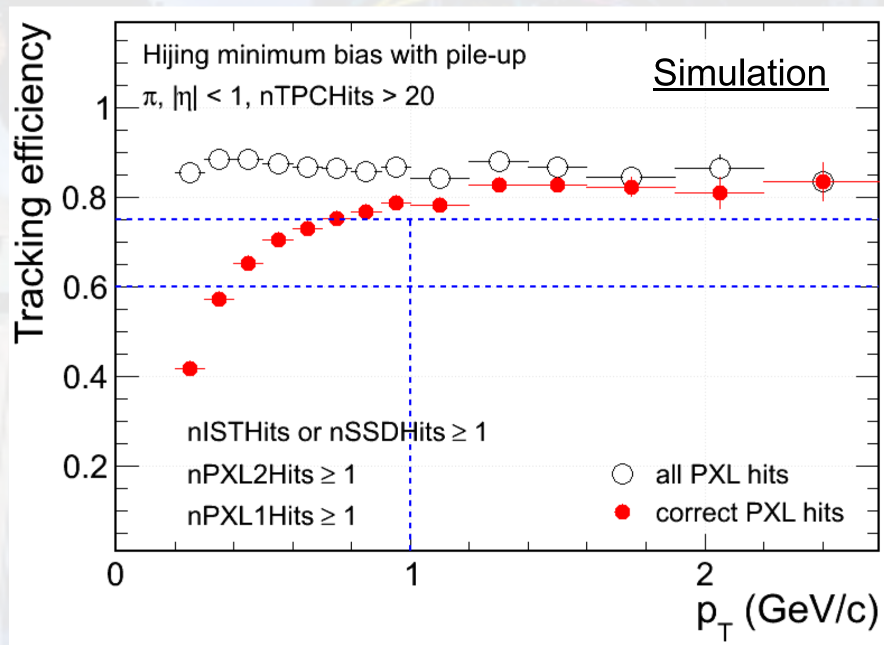
Simulation@50kHz

	PXL inner	PXL outer
Radius (cm)	2.8	8
MB pileup hits (cm^{-2})	13	~3
UPC electrons (cm^{-2})	33	~3
Total bkgd hits (cm^{-2})	46	~6
MB signal Au+Au (cm^{-2})	~8	~1
Au+Au MB real data (cm^{-2})	~50	~5

Signal hits fraction in MB (Central) events:
~15% (~30%) at PXL inner

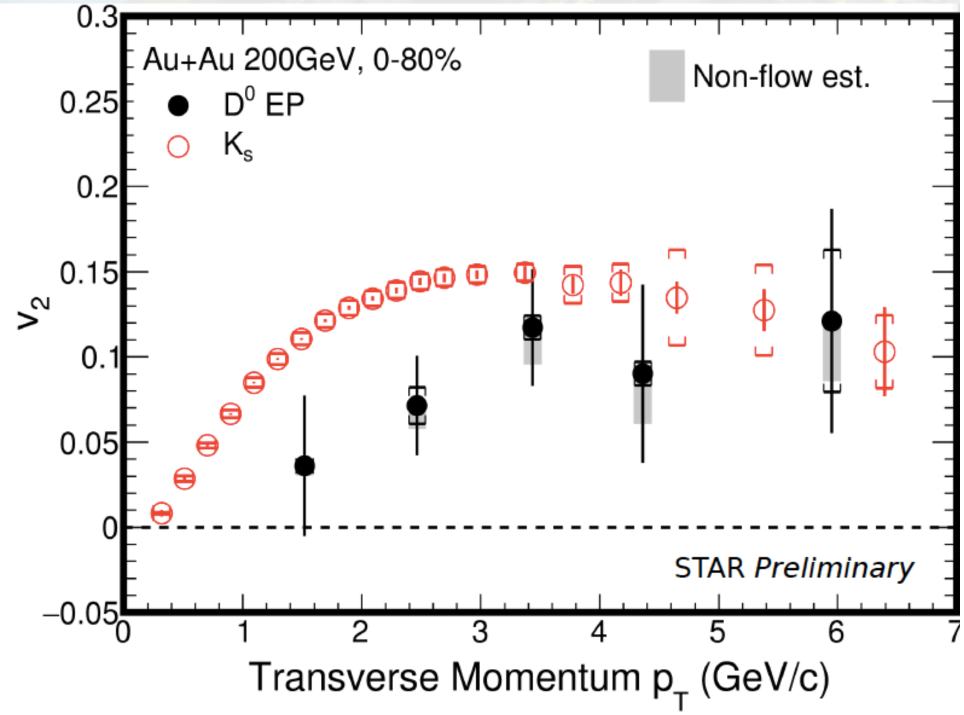
Increasing fake matches in low p_T

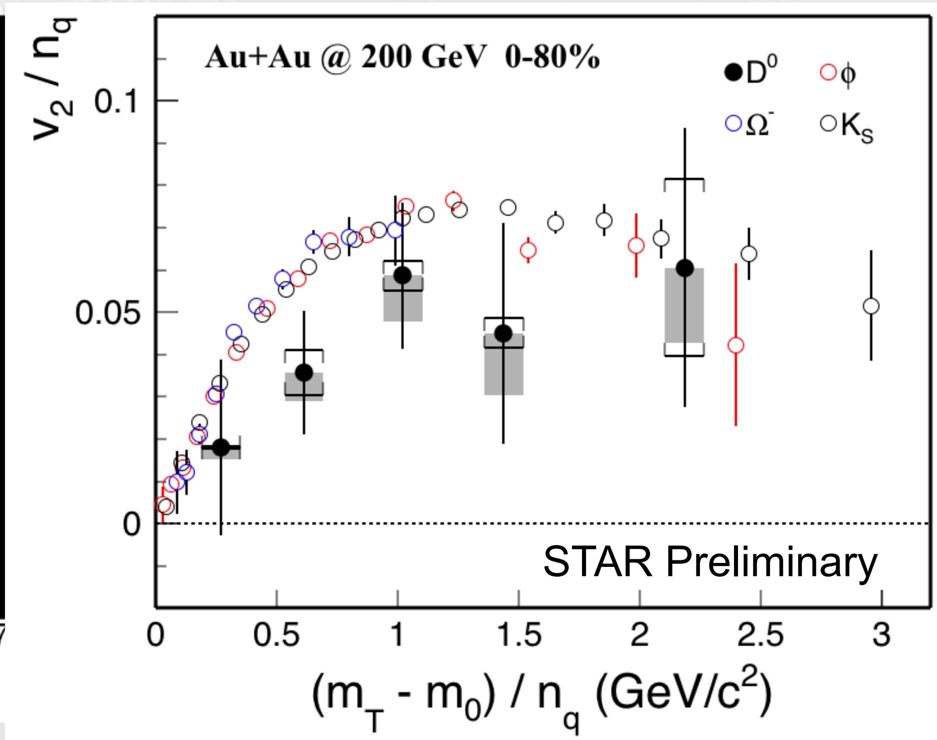
Technology chosen considering both physics and technology readiness



D-meson v_2 at RHIC

70% of 2014 Au+Au 200 GeV Data





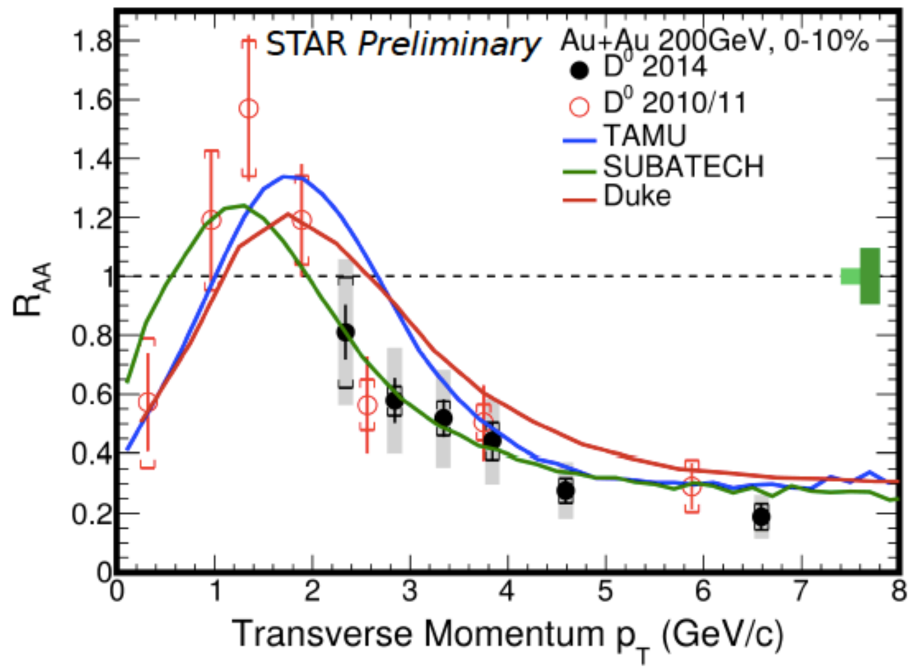
Significant charm hadron v_2 at p_T>2 GeV/c

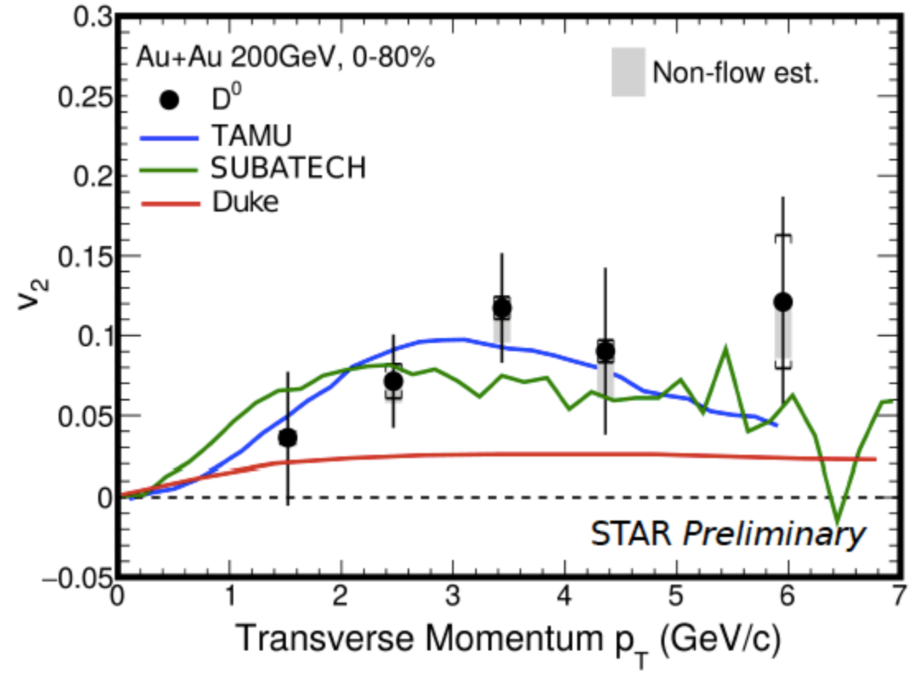
v_2/n_q vs. $(m_T-m_0)/n_q$: D-meson comparable to Ks, ϕ, Ω

- may be slightly lower: centrality bias

- (D ~ N_{bin} scaling, light hadrons ~ N_{part} scaling)

D^0 R_{AA} and v_2 Compared to Models

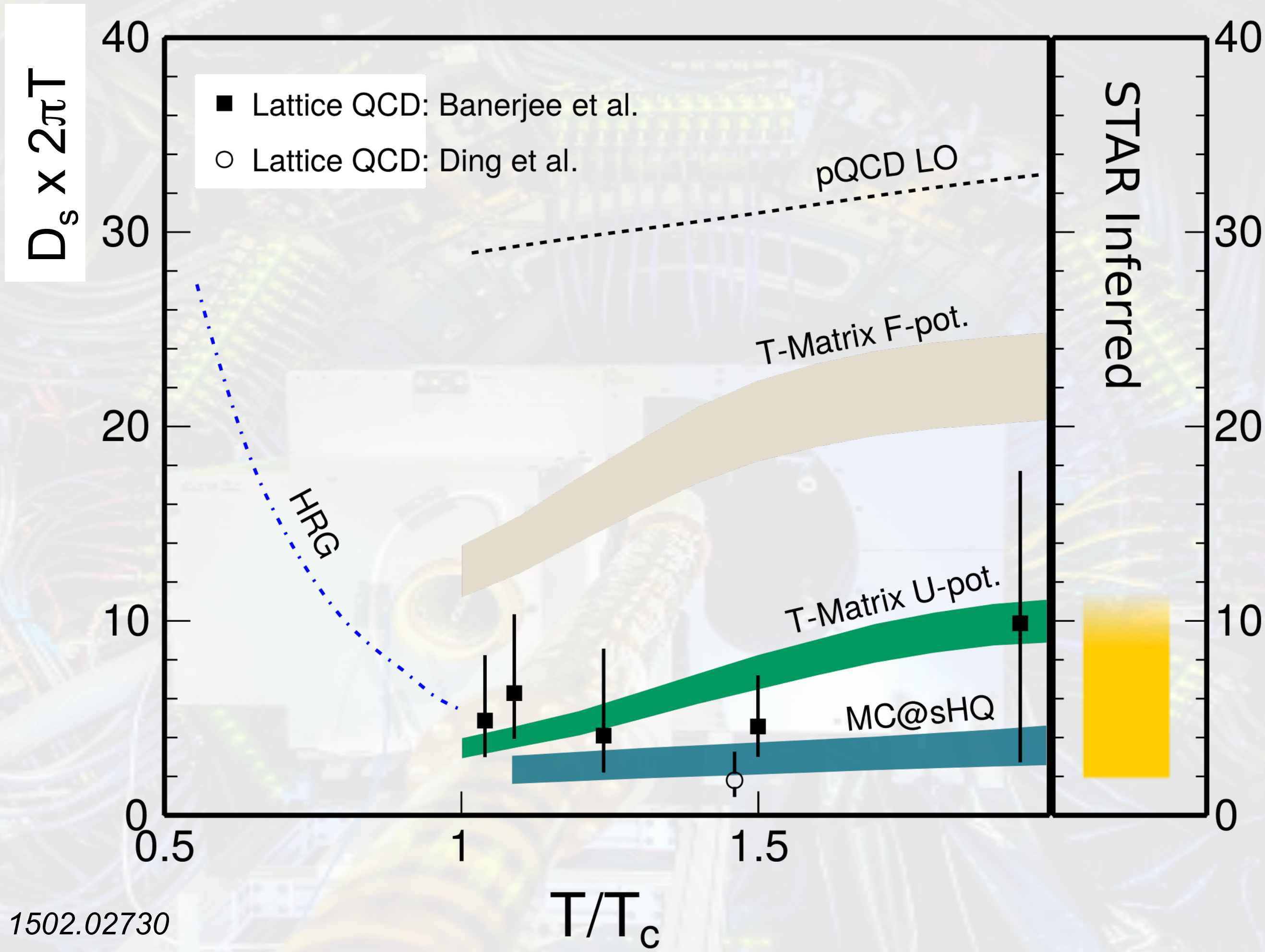




D-meson v_2 data favor charm quark diffusion / flow in the medium

Models with **charm flow** + **coalescence** describe both R_{AA} and v_2 data of D-mesons

Heavy Quark Spacial Diffusion Coefficient

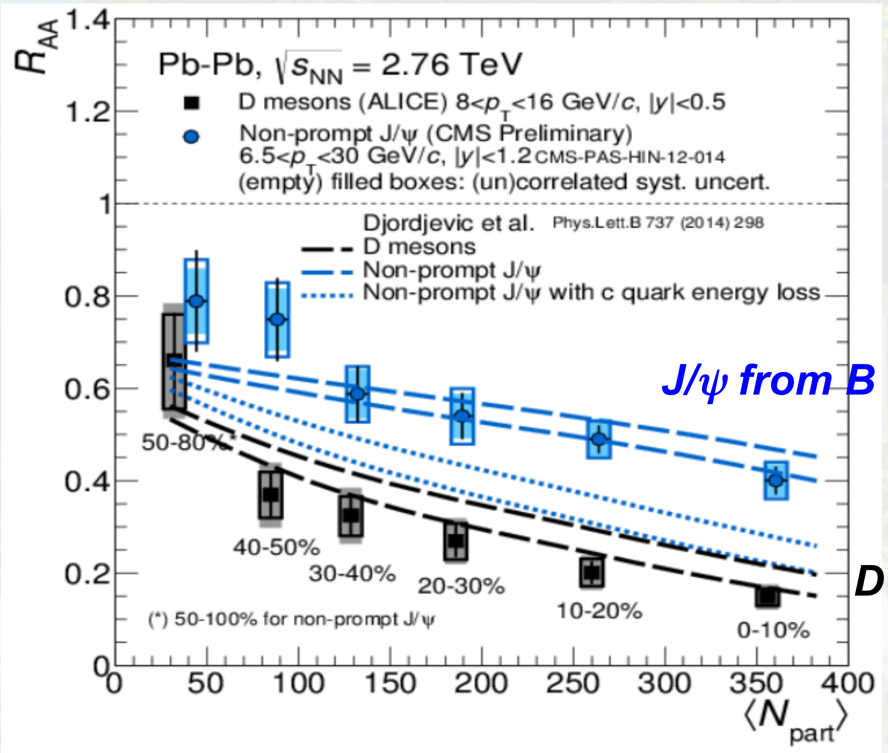


arXiv: 1502.02730

Data favors $2\pi T\boldsymbol{D_s}$ ~ 2-12 (temperature dependence)
- Consistent with lattice QCD calculations

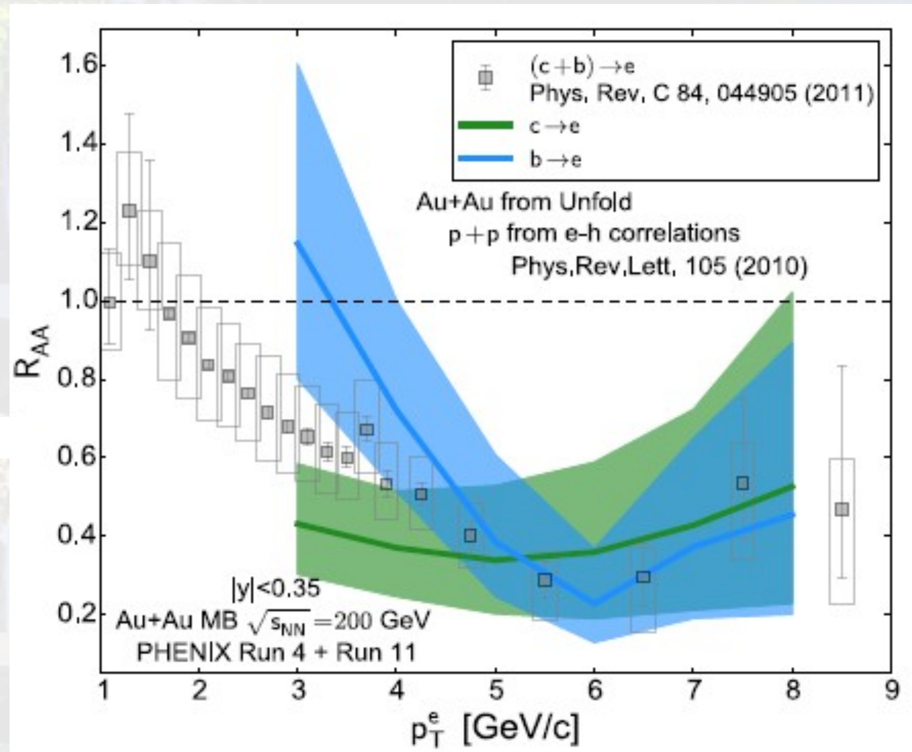
Bottom Suppression in Heavy Ion Collisions

LHC



CMS-PAS-HIN-12-014, ALICE JHEP 11(2015) 205

RHIC



PHENIX PRC 93 (2016) 034904

Suppression hierarchy between $R_{AA}(J/\psi^B)$ and $R_{AA}(D)$ at LHC
Hint of hierarchy between $R_{AA}(e^B)$ and $R_{AA}(e^D)$ at RHIC
– consistent with pQCD calculations

Open Bottom Production

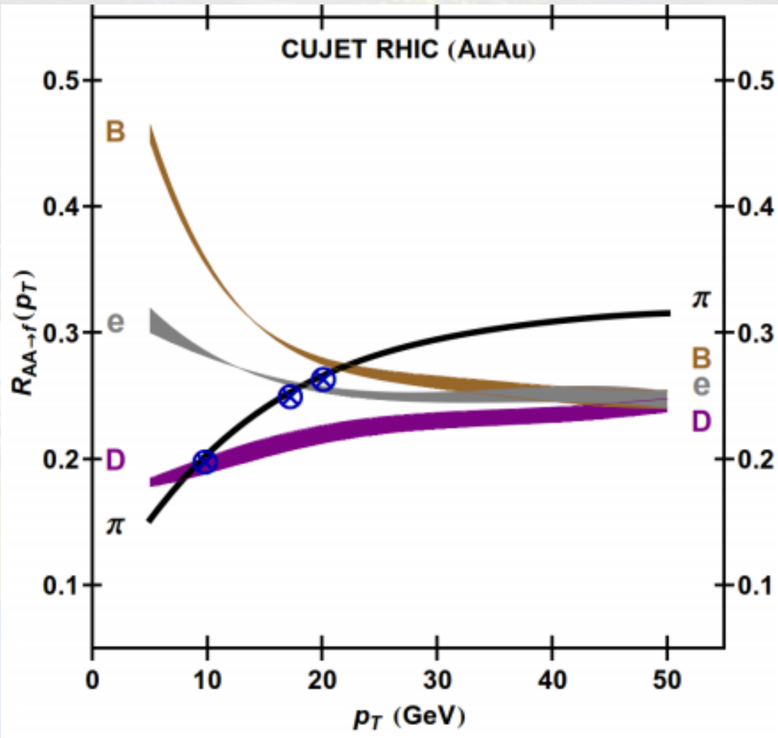
<u>Open bottom</u> production over a wide range of momentum

Flavor dependence of parton energy loss

Cleanest probe to quantify medium transport properties – e.g. $\boldsymbol{D_{HQ}}$

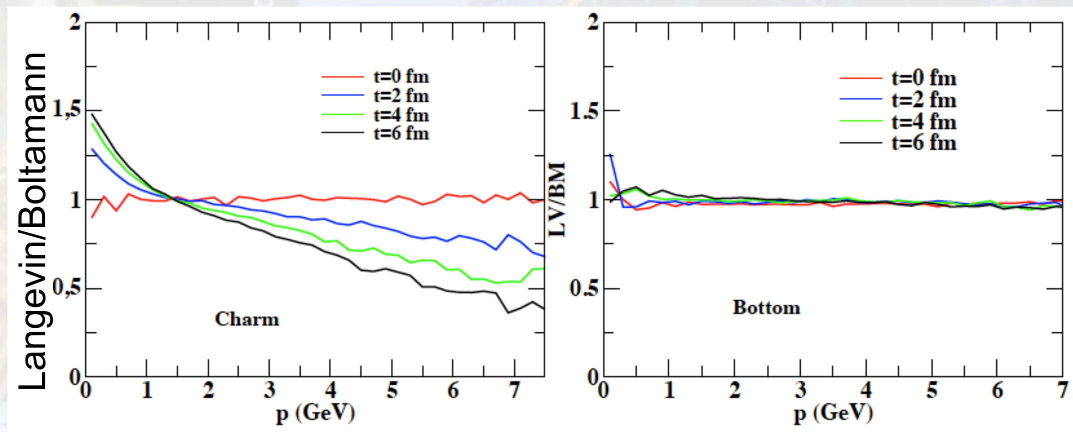
Total bottom yield for precision interpretation of Upsilon suppression

- low p_T coverage is critical



Buzzatti et al., PRL 108 (2012) 022301

Das et al., PRC 90 (2014) 044901



Is charm heavy enough?

Sizable correction to the Langevin approach for charm

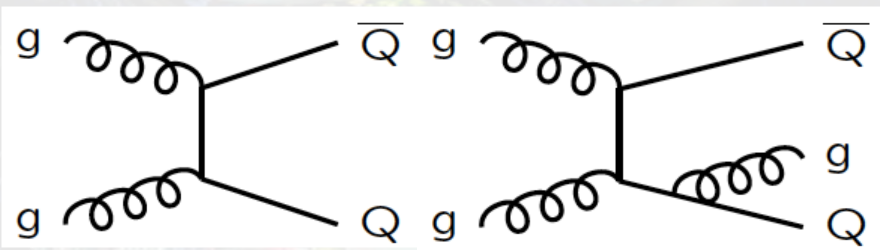
- may limit the precision in determining $\boldsymbol{D_{HQ}}$

Uniqueness at RHIC

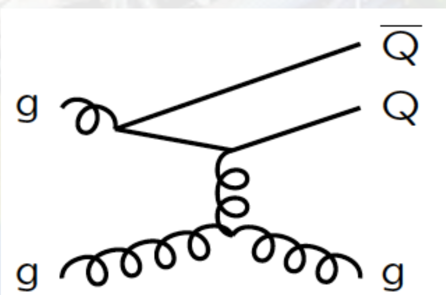
Uniqueness at RHIC

- dominated by pair creation, clean interpretation for experimental results

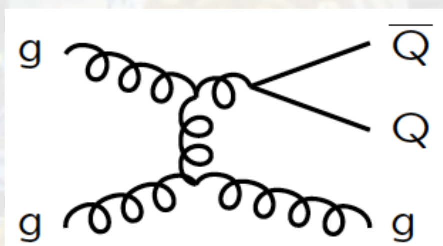
Pair Creation

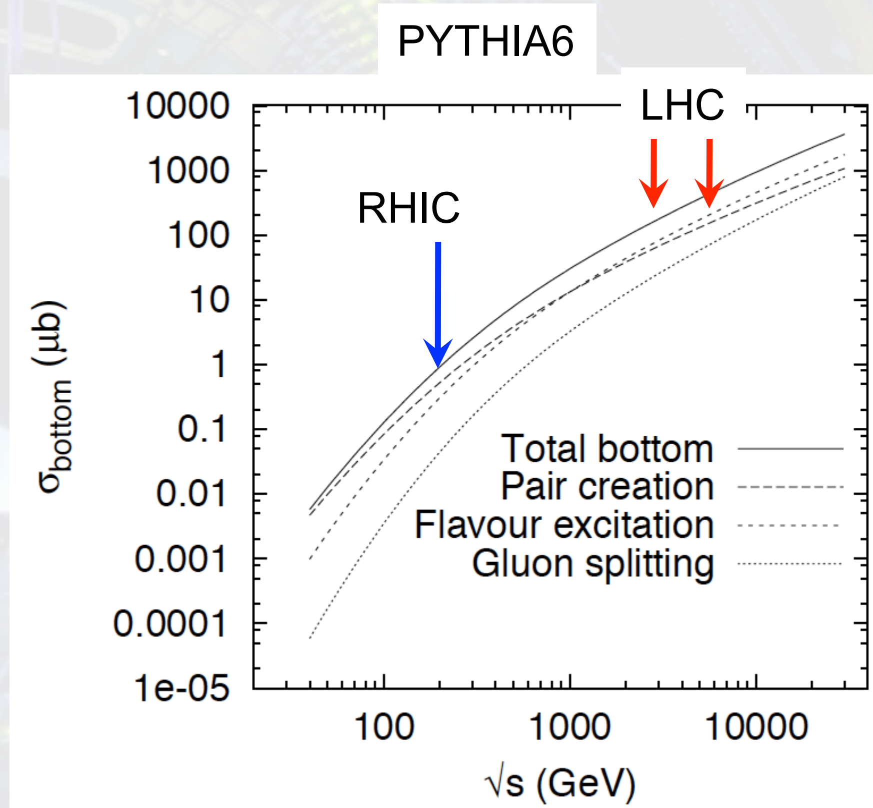


Flavor Excitation



Gluon Splitting

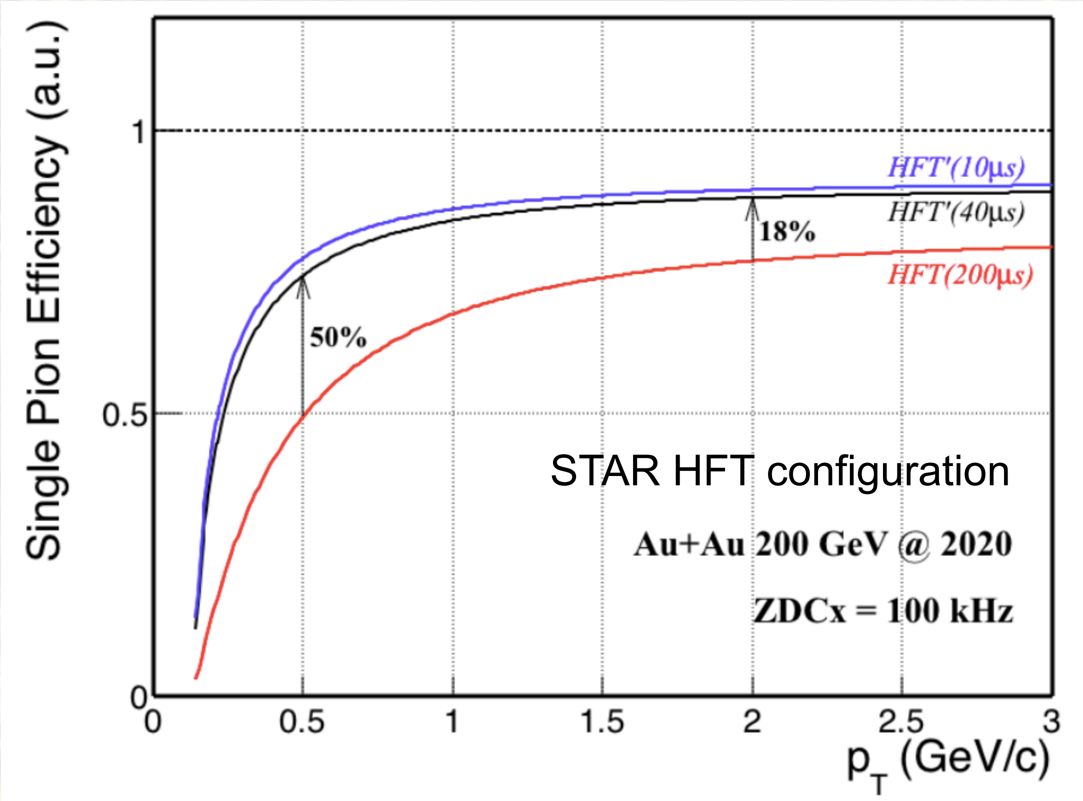




T. Sjostrand, EPJC17 (2000) 137

Requirements for Precision Open Bottom Production at RHIC

- High luminosity runs and large datasets (triggered and untriggered)
  B->J/ψ, B->D, B->e, B->Dπ and b-jet etc.
- Fast silicon detector with ultimate pointing resolution
  Next generation MAPS sensors with much shorter integration time < 20 μs (vs. 186 μs)
  - high efficiency at high RHIC luminosity, particularly at low p_T



Technology – ALICE MAPS for ITS-upgrade

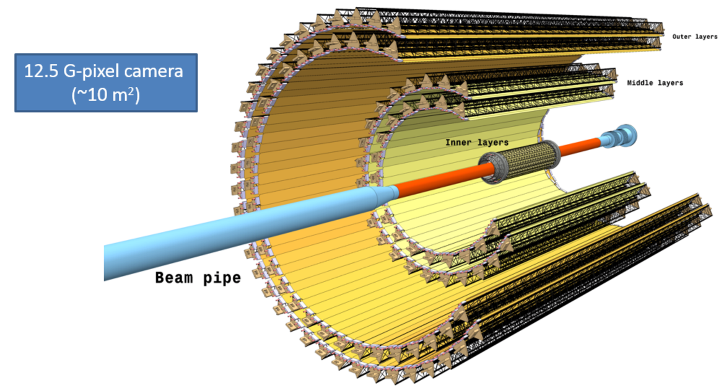
ALPIDE full-scale prototype ver.3 (Oct 2015)

Main parameters

- Dimensions: 30mm x 15 mm
- Pixel pitch: 29μm x 27μm
- Power consumption <100mW/cm^2
- Material thickness: 0.3X_0 (inner), 1X_0 (outer)
- Integration time: < 20 μs
- Total area 10 m^2 (PXL was 0.16 m^2)

New ITS Layout

ALICE



7-layer barrel geometry based on MAPS

r coverage: 23 – 400 mm

η coverage: $|\eta| \leq 1.22$
for tracks from 90% most luminous region

3 Inner Barrel layers (**IB**)

4 Outer Barrel layers (**OB**)

Material /layer : 0.3% X_0 (IB), 1% X_0 (OB)

7

LBNL RNC group is the project leader for the ALICE-USA ITS upgrade construction project.

- Assembly and testing of Middle layer staves (layers 3,4)
- RDO system design (collaboration) and fabrication of RDO for the middle layers.
- Design of the powering system for all outer layers (3-6)
- Sensor and component testing at the BASE facility for SEU and SEL.
- Outer layers carbon fiber support cylinder and services cone structures.

Physics Channels

Hadron	Abundance	$c\tau$ (μm)
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
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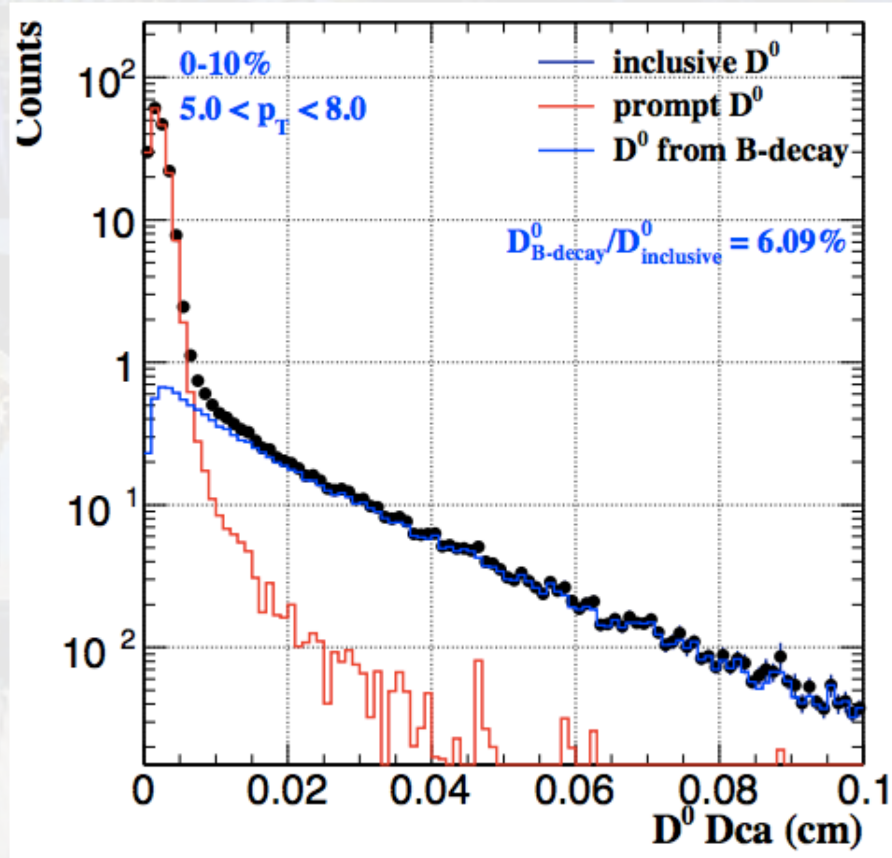
Simu. for STAR HFT



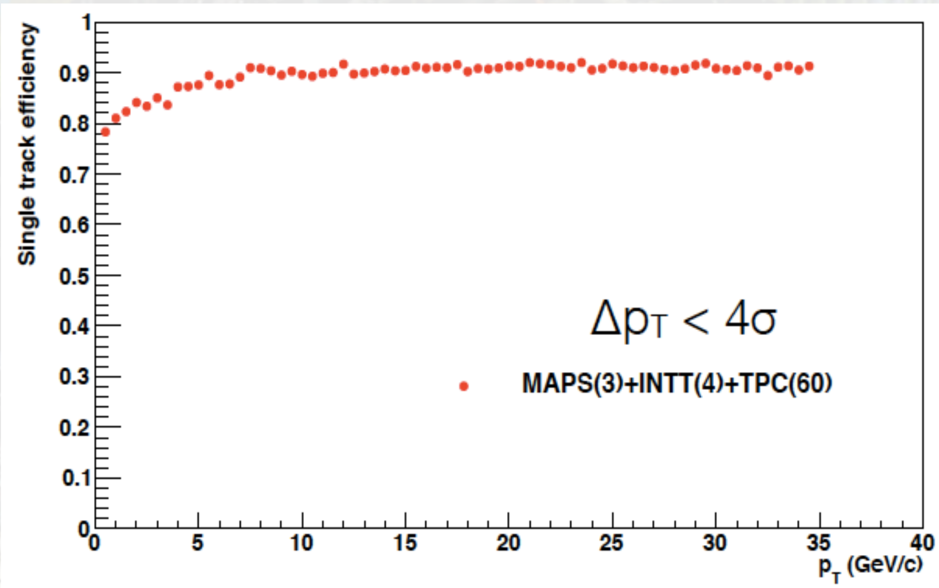
$$
\left.\begin{array}{ll}
B \to J/\psi + X & 1.2\% \\
B \to \overline{D}^0 + X & 60\% \\
B \to e + X & 11\% \\
B^+ \to \overline{D}^0 \pi^+ & 0.5\%
\end{array}\right\}
$$

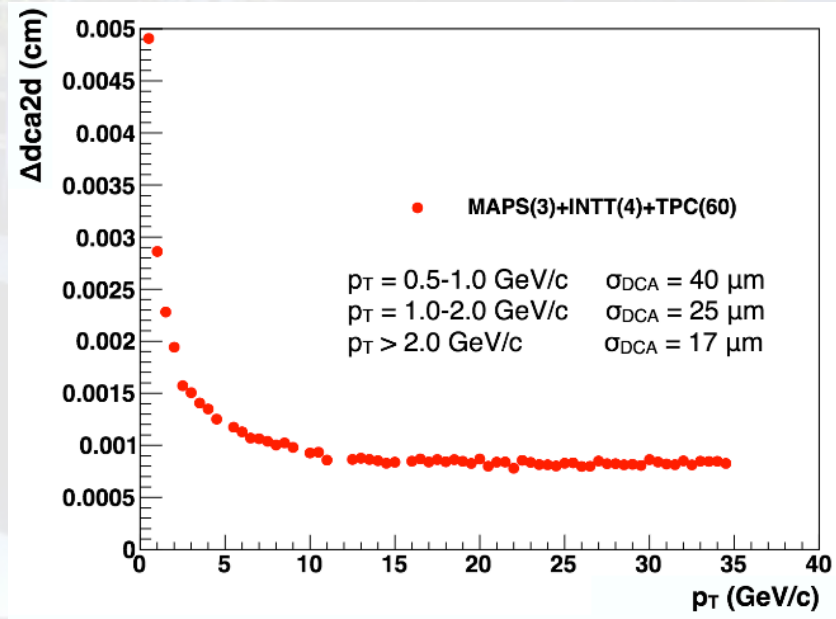
Needed for p_T<10 GeV

b-tagged jet *- see Jin's talk*

Tracking Performance Input for Quick Estimation

Input distributions coming from sPHENIX full GEANT simulation performance for single track with TPC+INTT+MAPS





T. Frawley, sPHENIX tracking review, Sept. 2016

A few assumptions - to be verified / fine-tuned with full GEANT simulation

- Low p_T efficiency drop due to fake matches
- Same/comparable resolution in DCA_z dimension, and the correlation between DCA_xy and DCA_z taken from STAR HFT
- The broader DCA structure (due to fake matches) taken from STAR TPC+HFT (conservative)

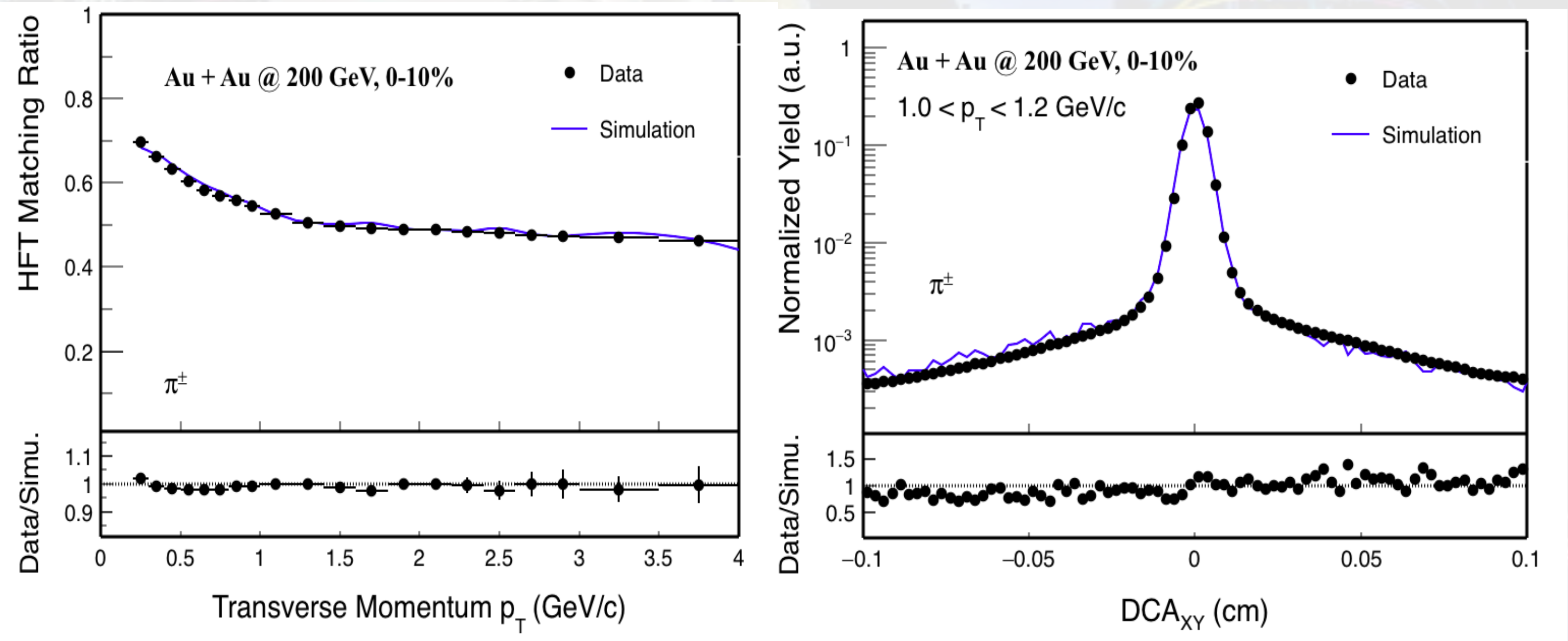
A Bit Detail on the Simulation Estimation

• A fast simulation approach (package used for HFT efficiency calculation too)

- tracking efficiency characterized by a matching ratio between silicon detectors and the TPC
- full DCA distributions represent the tracking performance (including good and mis-matches) – 2D (DCA_xy vs. DCA_z)

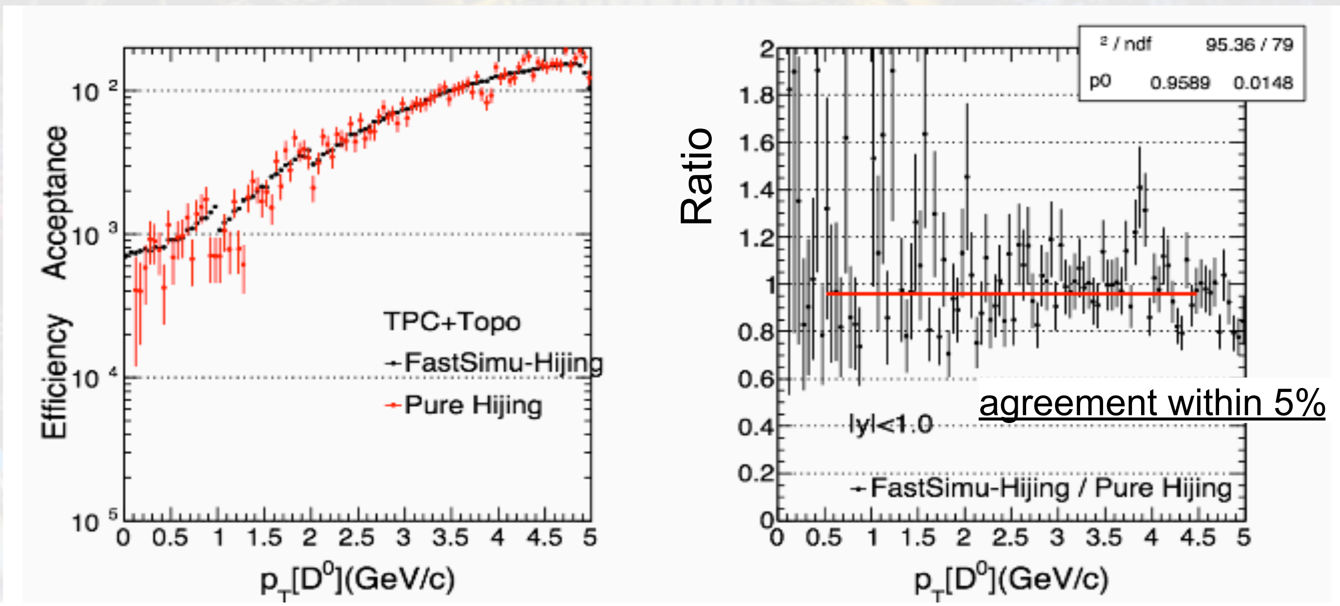
Goal: to capture full distributions for both signals and combinatorial backgrounds
- reasonably good for low p_T estimation

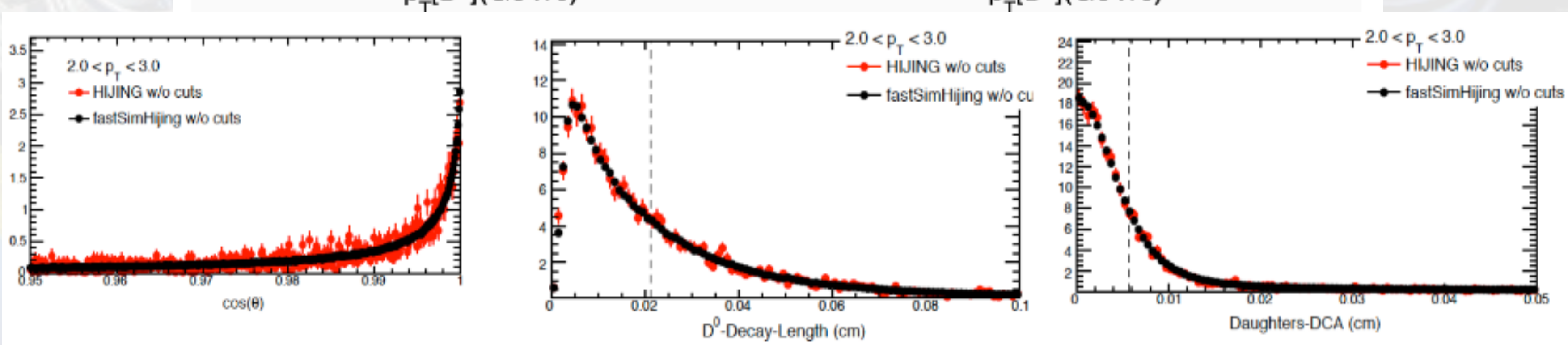
Examples for STAR HFT



Validation with Full GEANT Simulation

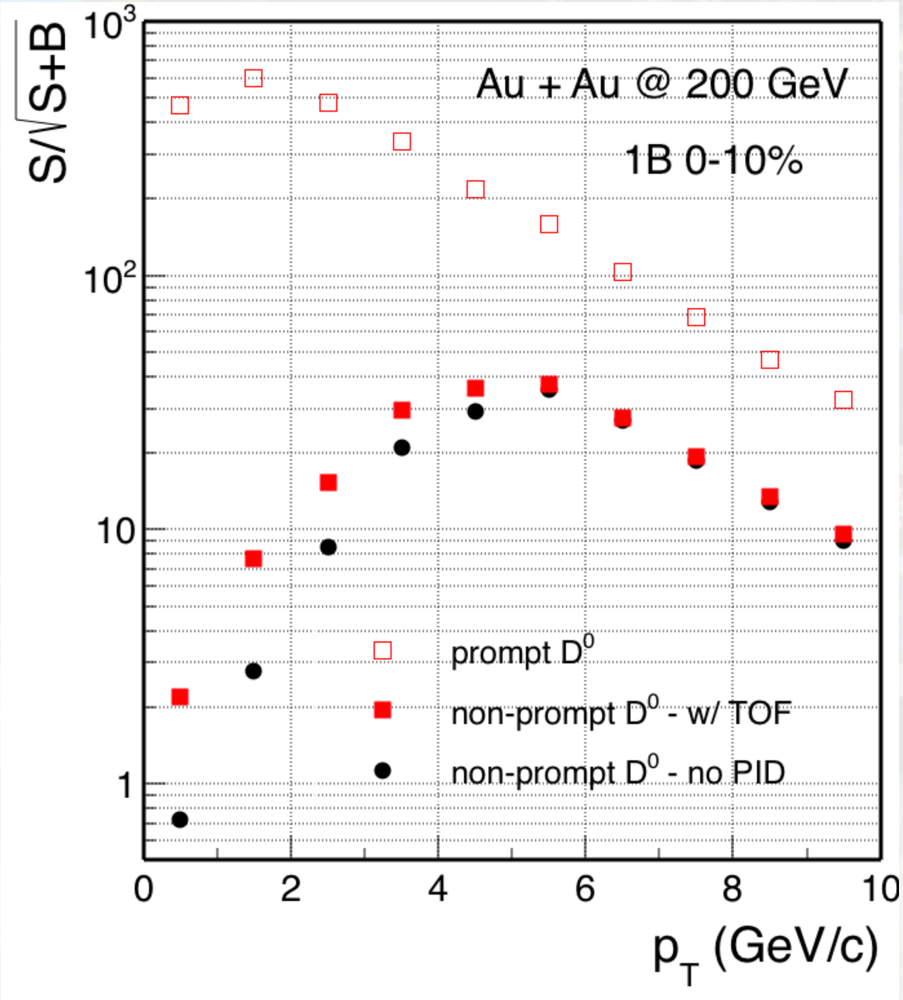
- Hijing+D^0 sample through GEANT + reconstruction
- Fast simu – inputs taken from Hijing single track performance
- Then compare the efficiencies between fast simu vs. that from Hijing+GEANT directly

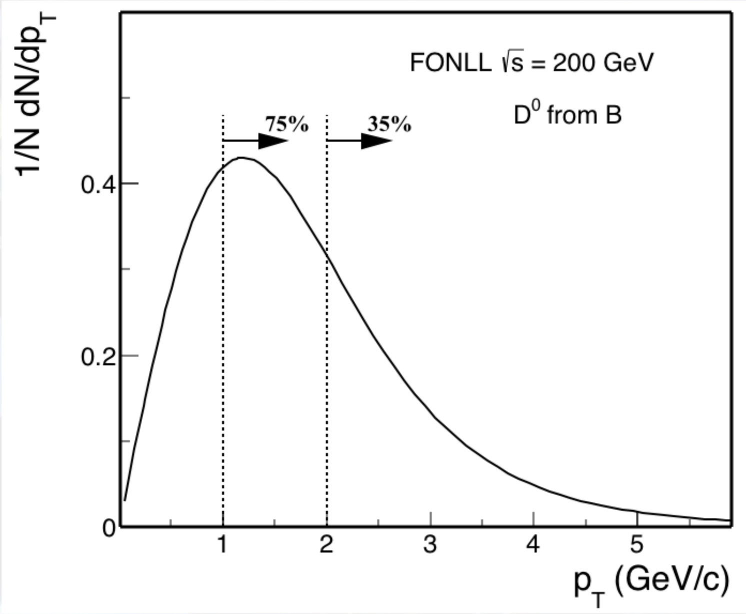




Estimation for Non-prompt D^0 at sPHENIX

D^0 significance in 1B 0-10% Au+Au events



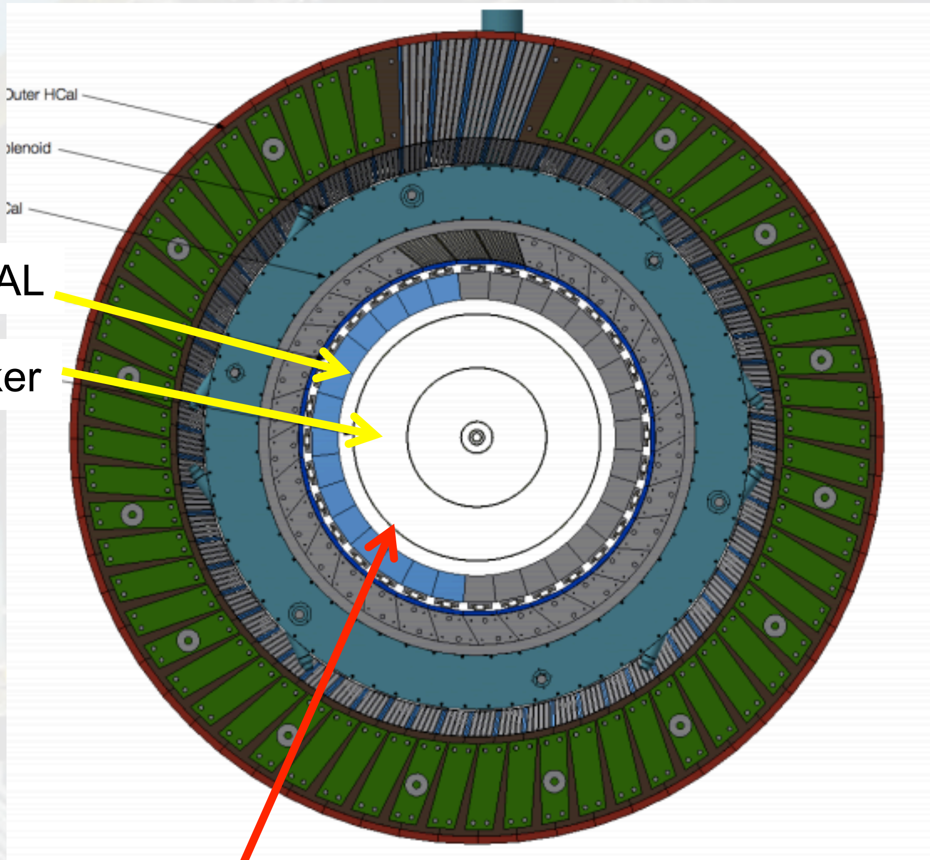


D^0 cross section – fit to STAR measurement
Bottom cross section – FONLLN_{bin}*

Good performance for measuring non-prompt D^0 at low p_T with sPHENIX

PID detector (TOF) can help further improve the low p_T precision
- constrain the total bbbar X-sec

Particle Identification with TOF



EMCAL

Tracker

10cm gap between TPC and EMCAL - TOF

TOF PID requirement:

$$M = p\sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

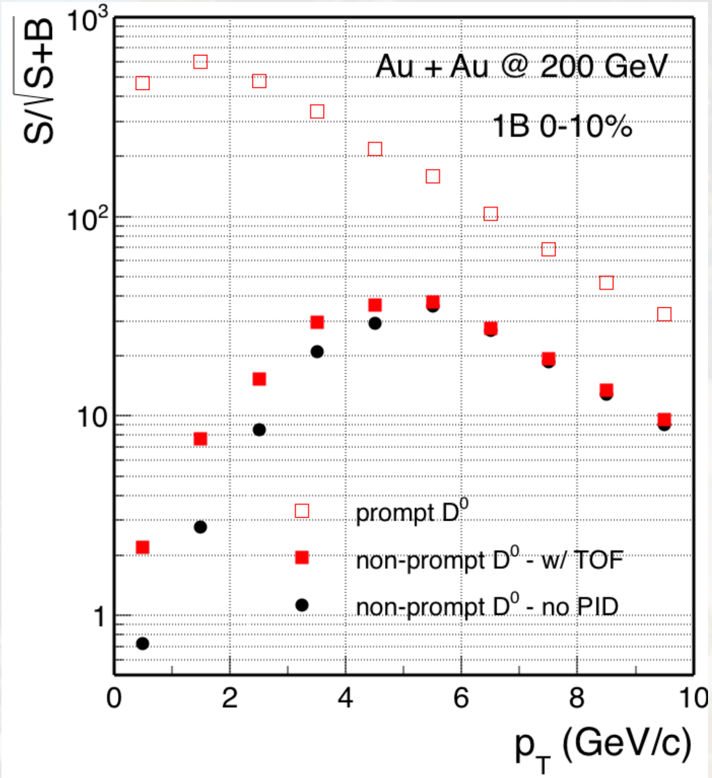
$$\frac{\Delta M}{M} = \frac{\Delta p}{p} \oplus \gamma^2 \left[\frac{\Delta L}{L} \oplus \frac{\Delta t}{t}\right] \sim \gamma^2 \frac{\Delta t}{t}$$

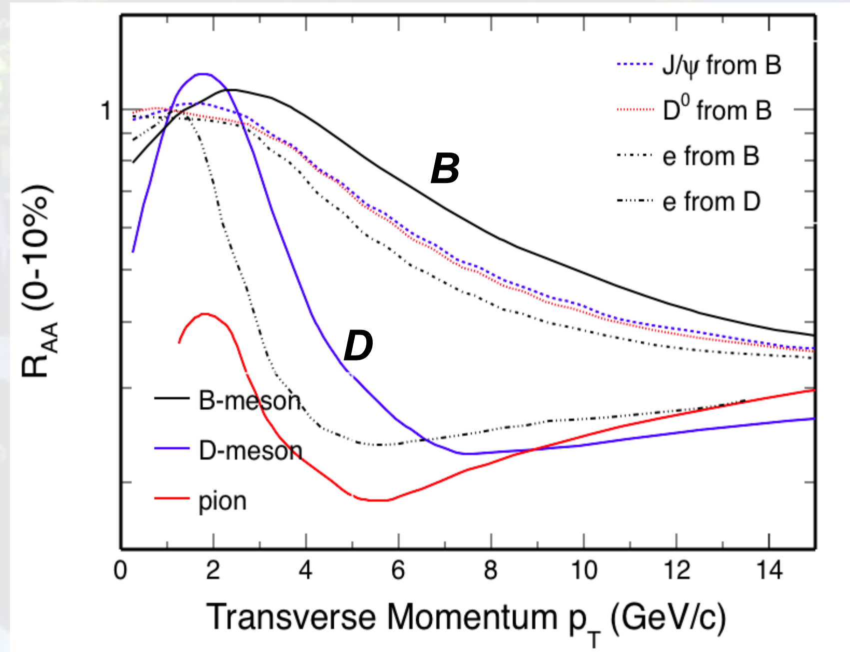
STAR TOF:
Radius ~ 2.15 m, σ_t ~ 65 ps

sPHENIX TOF
(to have the same PID capability)
Radius ~ 0.85 m, **σ_t ~ 25 ps**

Candidate: Many-gap MRPC

Physics Simulation To-Do List towards Proposal





Theory curves on B/D-mesons from TAMU/DUKE/CUJET

- Realistic estimation on the pileup MB/UPC hit density at MAPS sensors.
- Full GEANT simulation to obtain the complete input distributions for data-driven fast simu.
- Estimation of uncertainties on R_{AA}/R_{cp} etc.
  - Vertex resolution/efficiency effect in low multiplicity Au+Au and p+p collisions
- Decay channels B->D, B->J/ψ, B->e and B->Dπ etc.

Other HF measurements, e.g. Λ_c, HQ correlations etc.

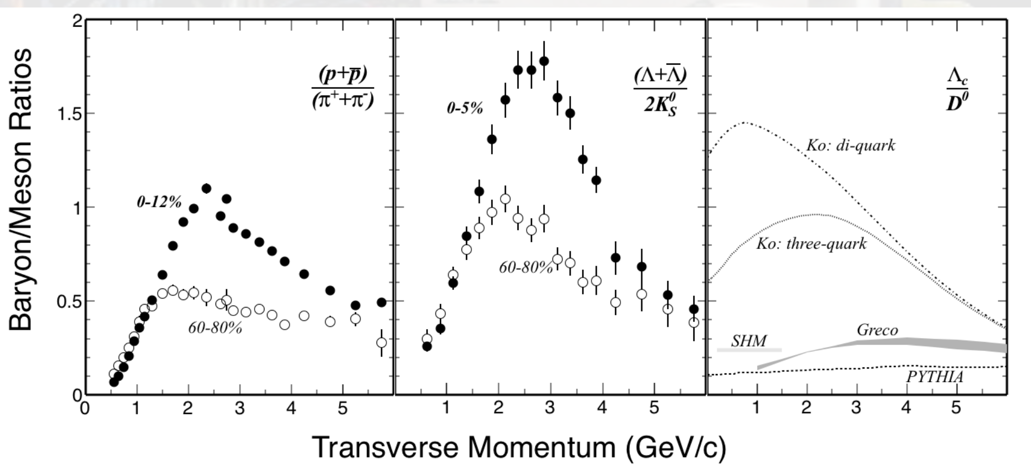
Λ_c and HQ Correlations

High statistics Λ_c measurements

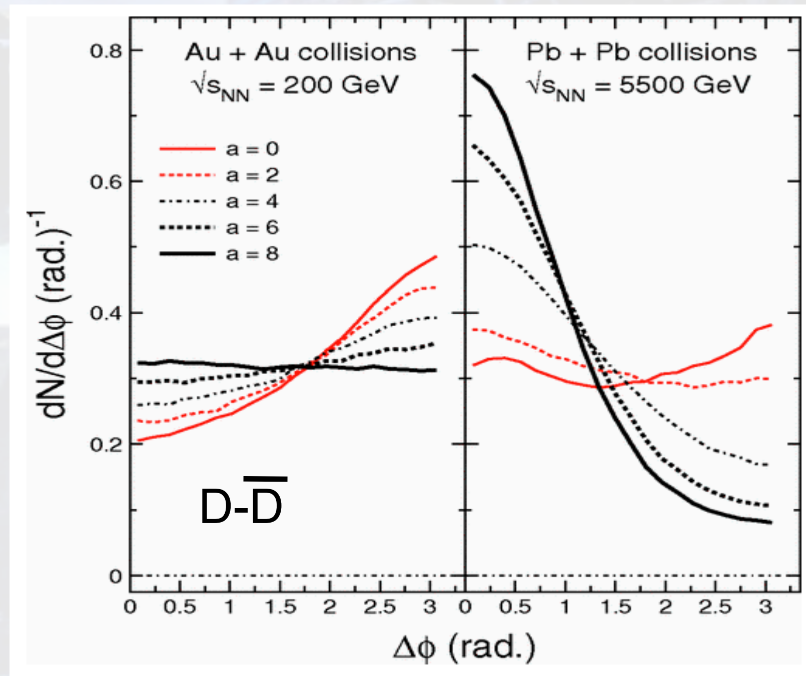
Λ_c/D^0 enhancement sensitive to
- charm quark hadronization, thermalization, domains in sQGP etc.

Heavy quark correlations

- More sensitivity to HQ-medium interaction, thus better determination of ΔE mechanisms and $\boldsymbol{D_{HQ}}$
- LHC vs. RHIC – different initial pair correlation/medium dynamics



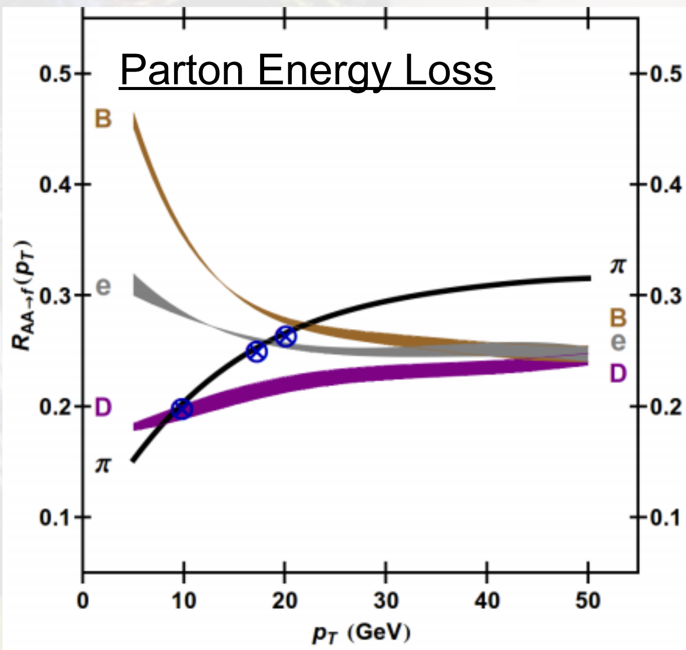
Lee et al, PRL 100 (2008) 222301
Ghosh et al, PRD 90 (2014) 054018



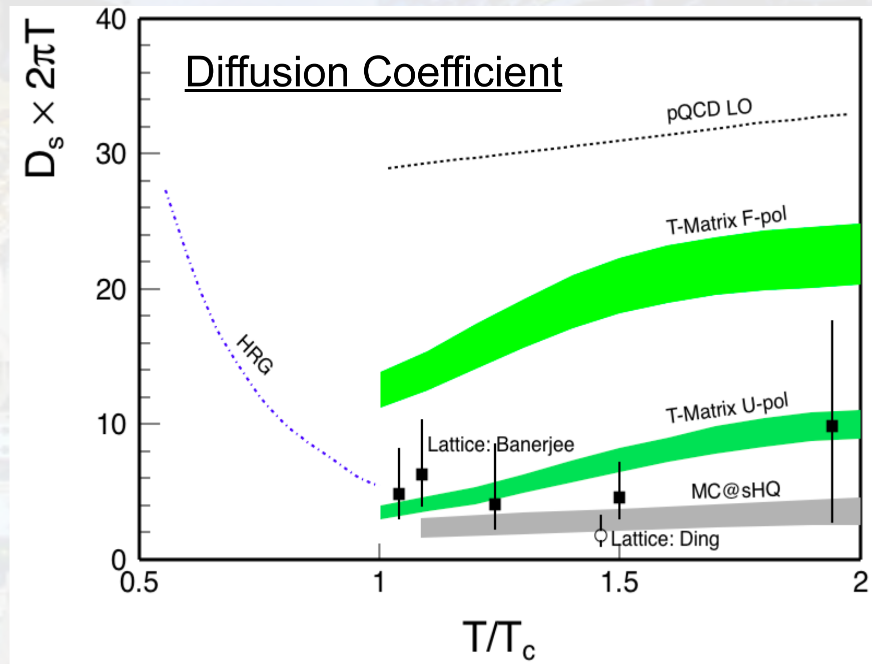
Zhu et al, PRL 100 (2008) 152301

Summary

- Heavy-flavor phase-I program at RHIC (2014-2016)
  - Precision charmed hadron measurements from STAR-HFT/PHENIX-(F)VTX
- Heavy-flavor phase-II program at RHIC (2021+)
  – Open bottom / correlation measurements
  - Complementary to the HF program at LHC
- Fast MAPS silicon detector is necessary and will deliver the physics



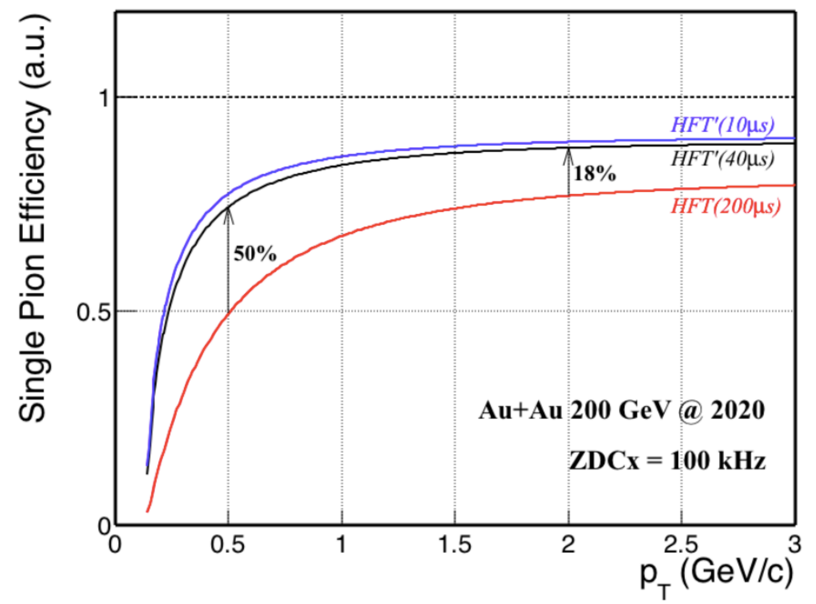
Buzzatti et al., PRL 108 (2012) 022301

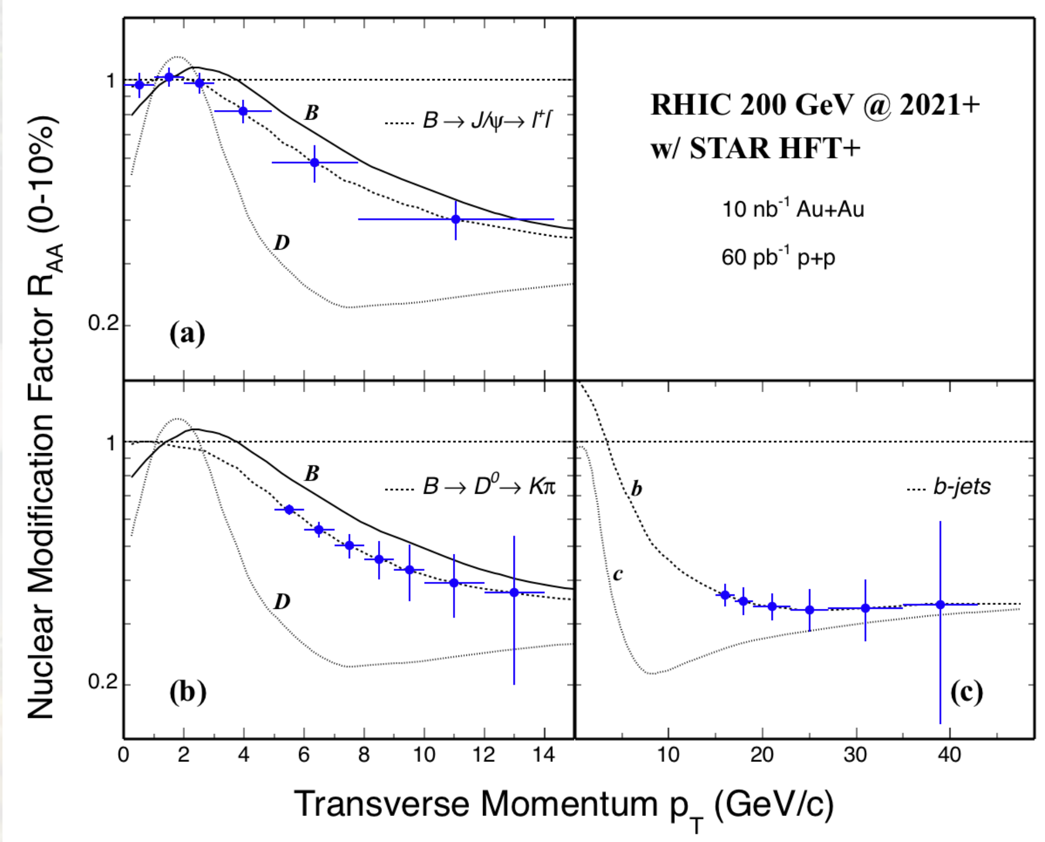


arXiv: 1502.02730, 1506.03981

Backups

Fast MAPS Detectors at RHIC – STAR HFT+

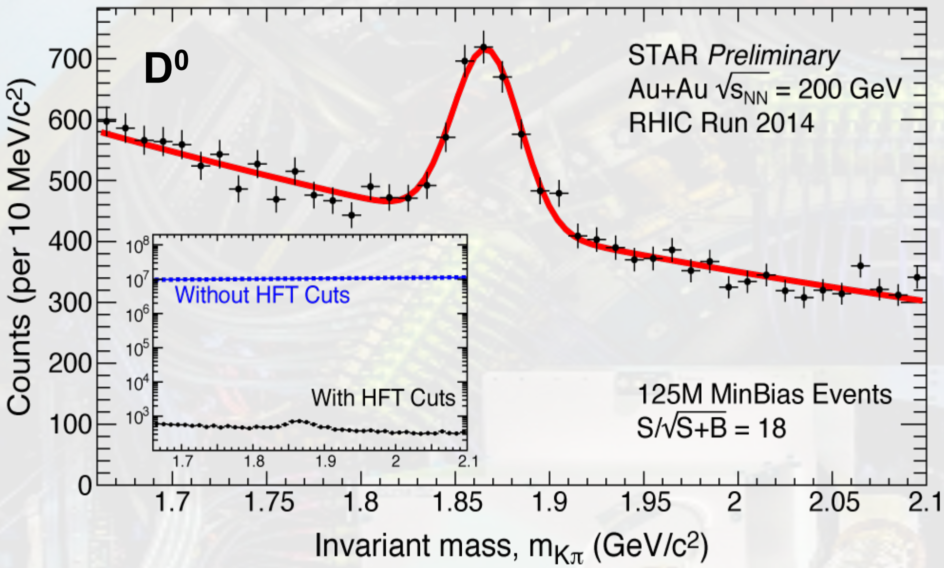


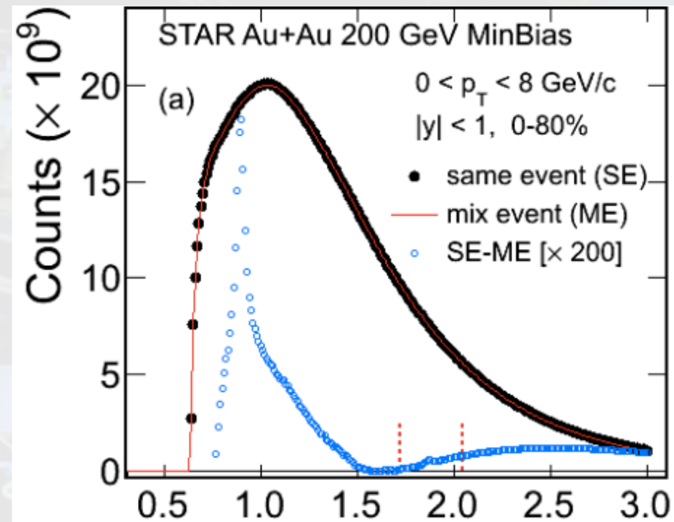


STAR HFT+ upgrade / sPHENIX pixel detector:
- Faster (<20μs) MAPS sensors – benefiting from ALICE ITS upgrade
- Aim for precision bottom measurements in 2021+ at RHIC

Complementary to LHC heavy flavor program

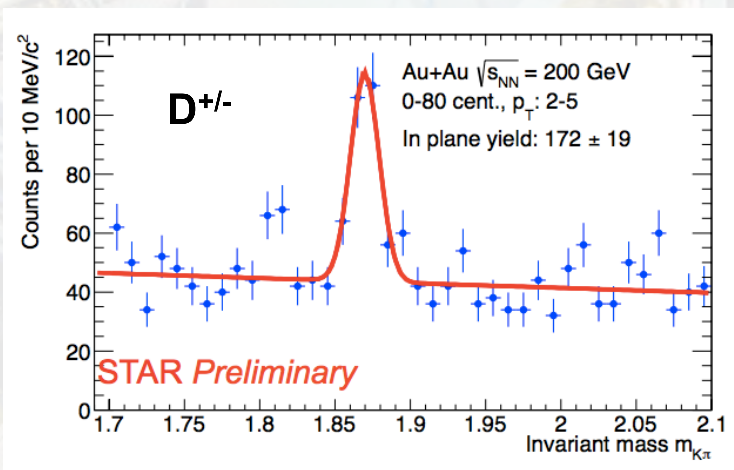
Pixel Detector Performance

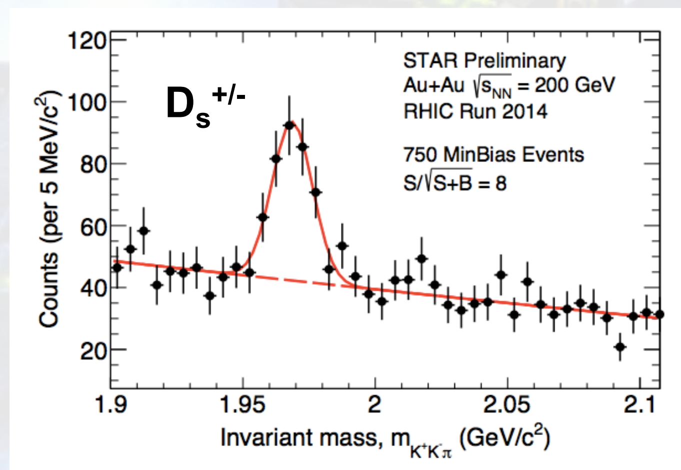




STAR, PRL 113 (2014) 142301

Significant improvement in S/B in D-meson reconstruction





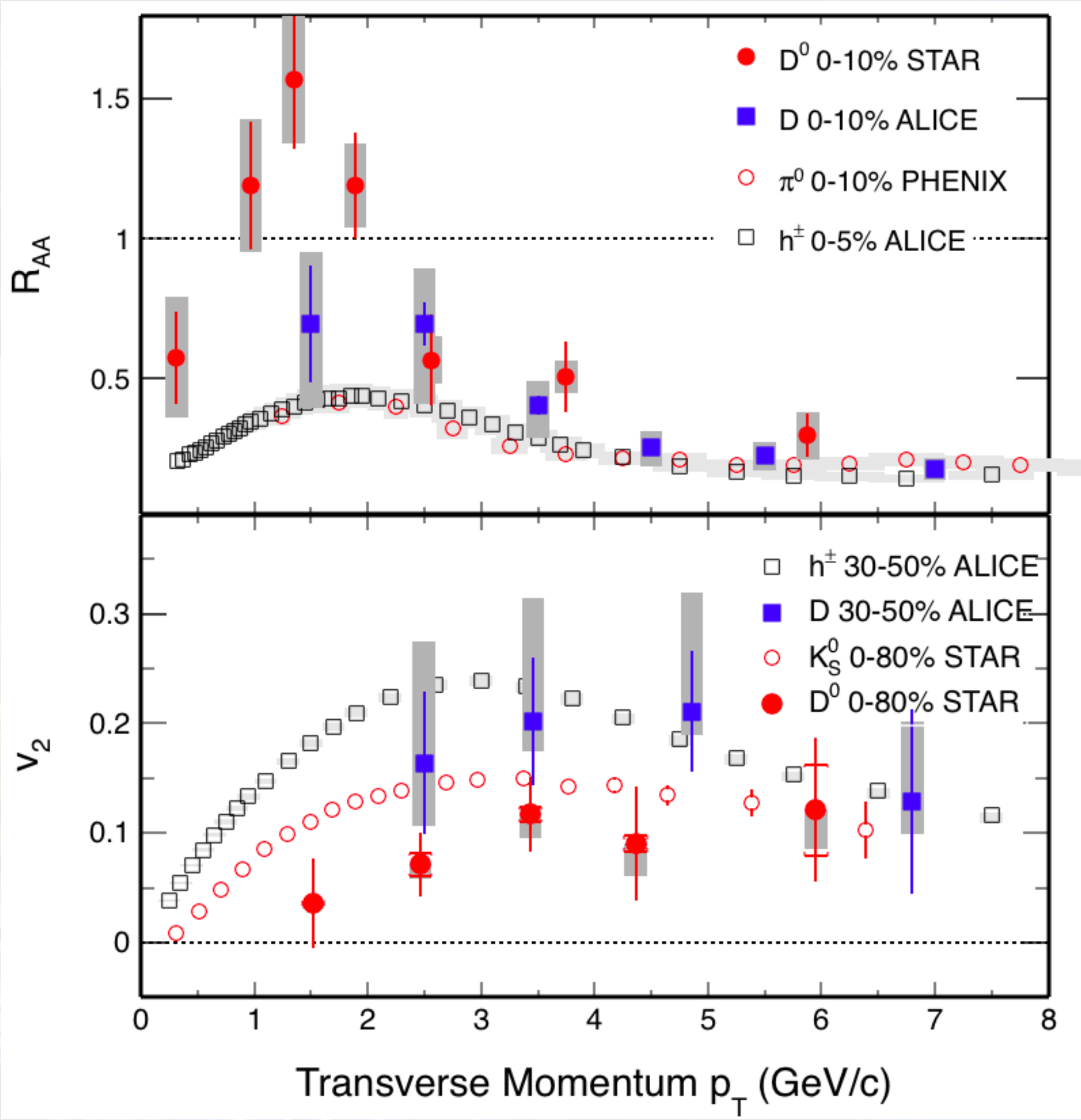
D-meson R_{AA} and v_2: RHIC vs. LHC

Comparable suppression at high p_T

- collisional and radiative ΔE

Possibly different physics at low p_T

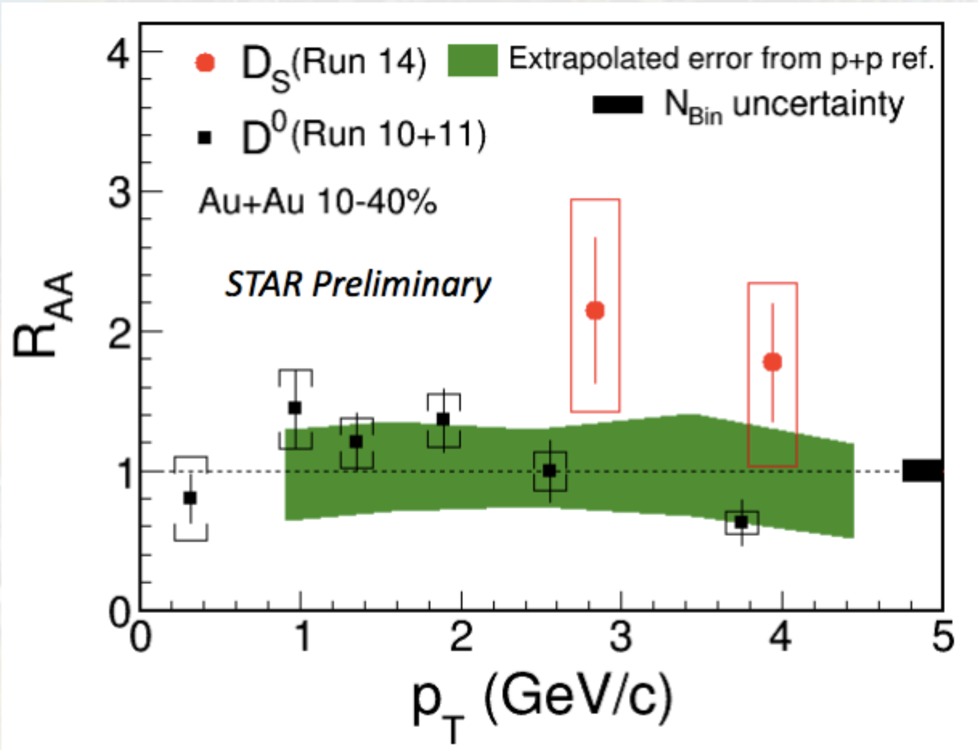
- Initial parton distributions
  x_T at 2 GeV/c ~ 10^{-2} (RHIC)
  ~ 10^{-3} (LHC)
- "Cronin" effect
- Charm quark flow



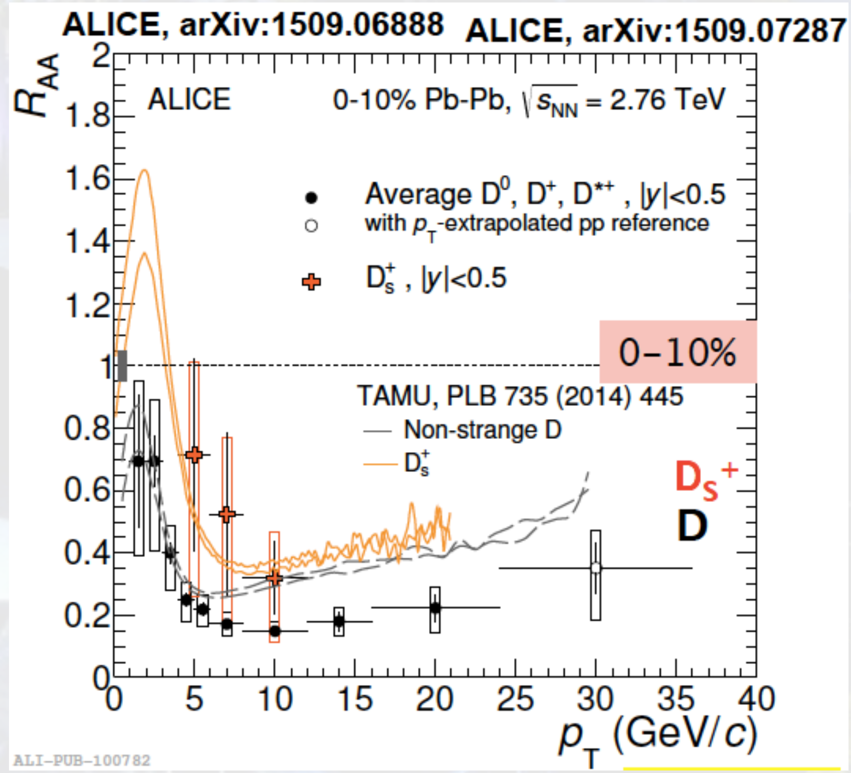
Precision charm v_2 data, particularly to low-intermediate p_T are critical for the extraction of sQGP D_{HQ}.

D_s – Hadronization and Strangeness Enhancement

RHIC



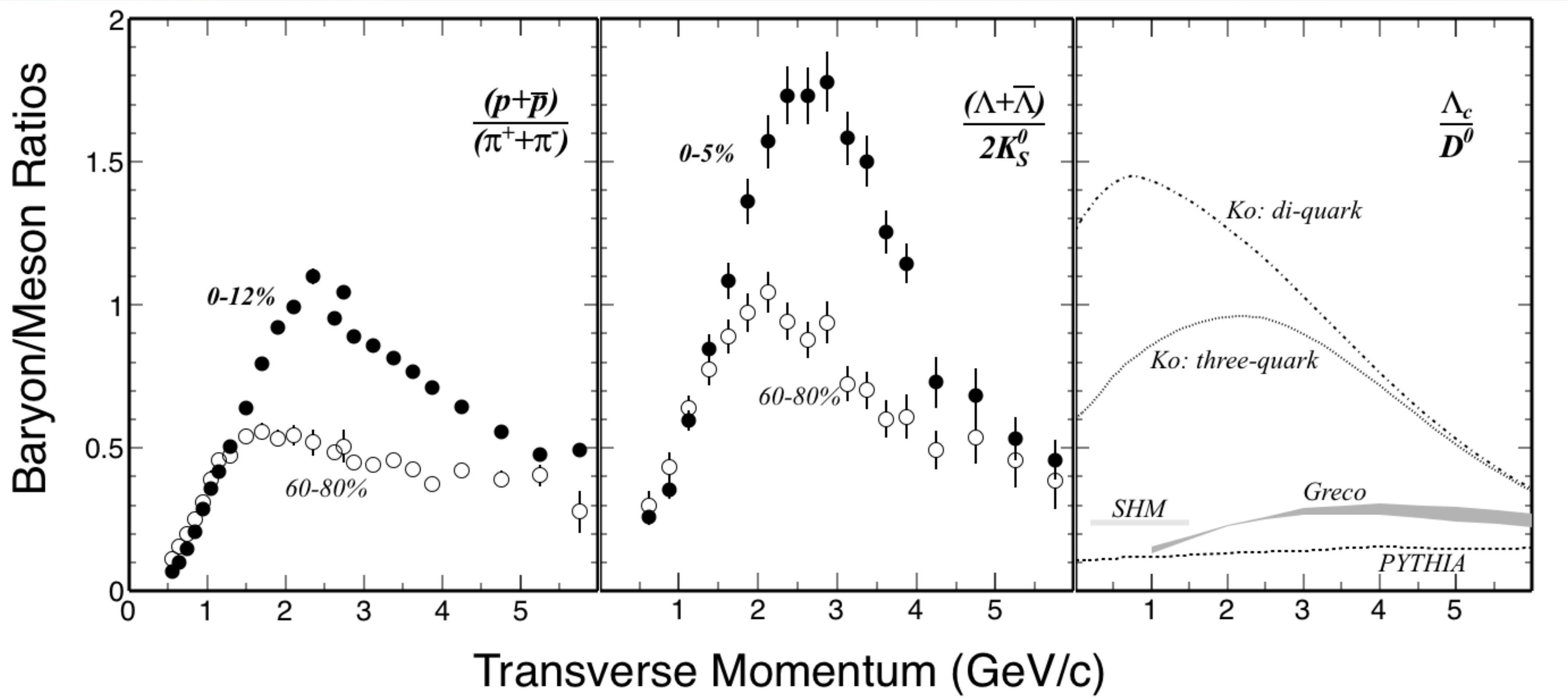
LHC



Strangeness enhancement in QGP + coalescence -> D_s/D^0 enhancement in HI collisions

Hint of D_s/D^0 enhancement in data from RHIC and LHC -> need more precise measurements

Λ_c - Charm Baryon Enhancement?



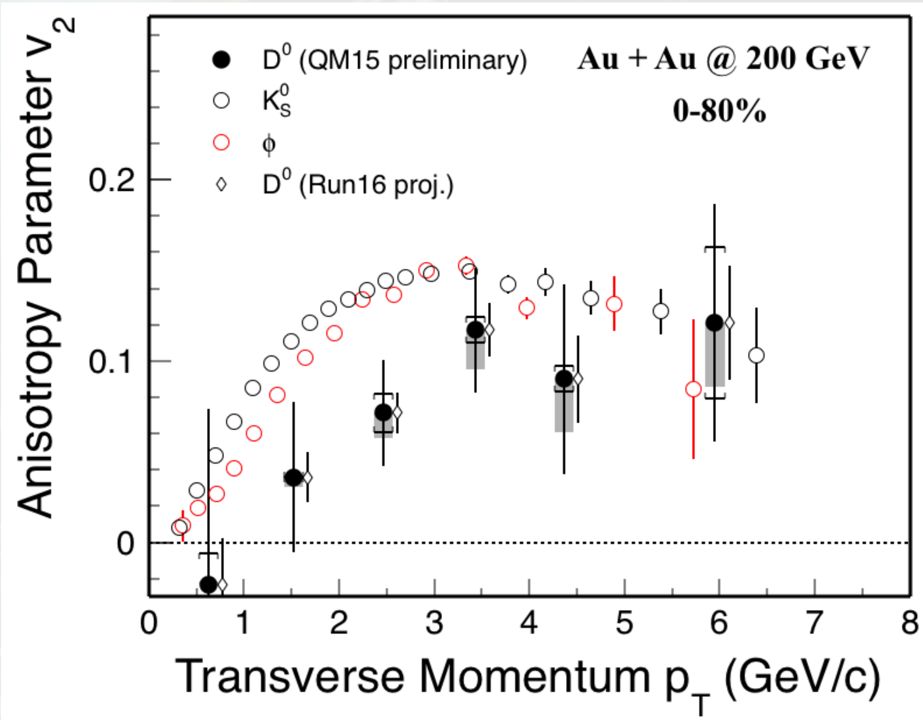
Various models predict different levels of enhancement for Λ_c/D^0 depending on
- hadronization, thermalization, domains in sQGP

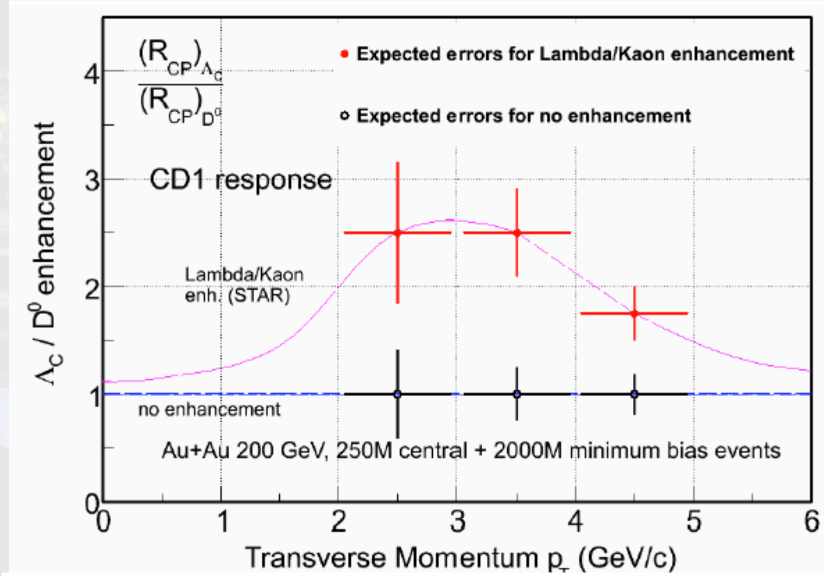
No measurement of Λ_c in A+A collisions ($c\tau$ ~ 60 μm, $\Lambda_c^+ \rightarrow pK^-\pi^+$, B.R. 5%)

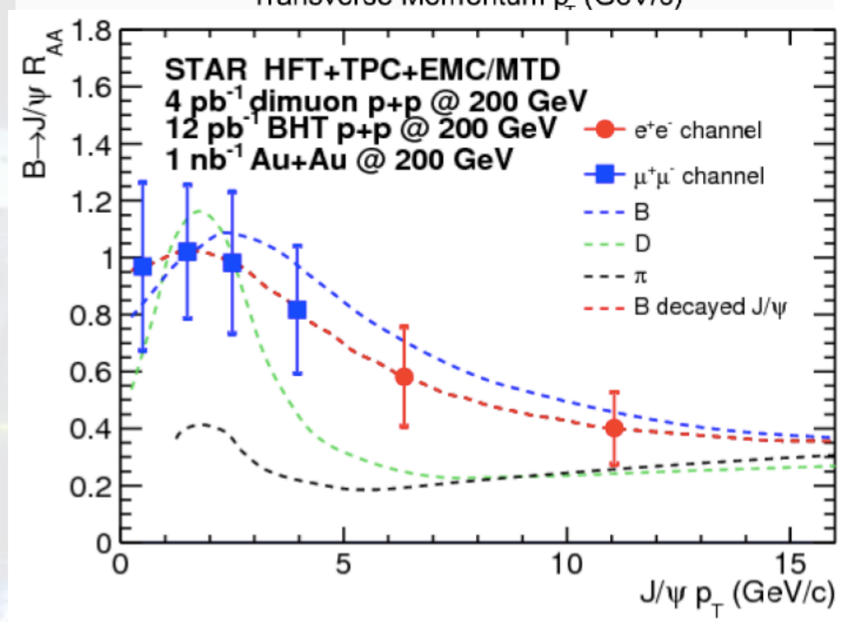
Prospective with the STAR HFT data at RHIC

Λ_c/D^0: Lee et al., PRL100 (2008) 222301; Ghosh et al., arXiv:1407.5069

Near-Term: STAR HFT Physics Goals





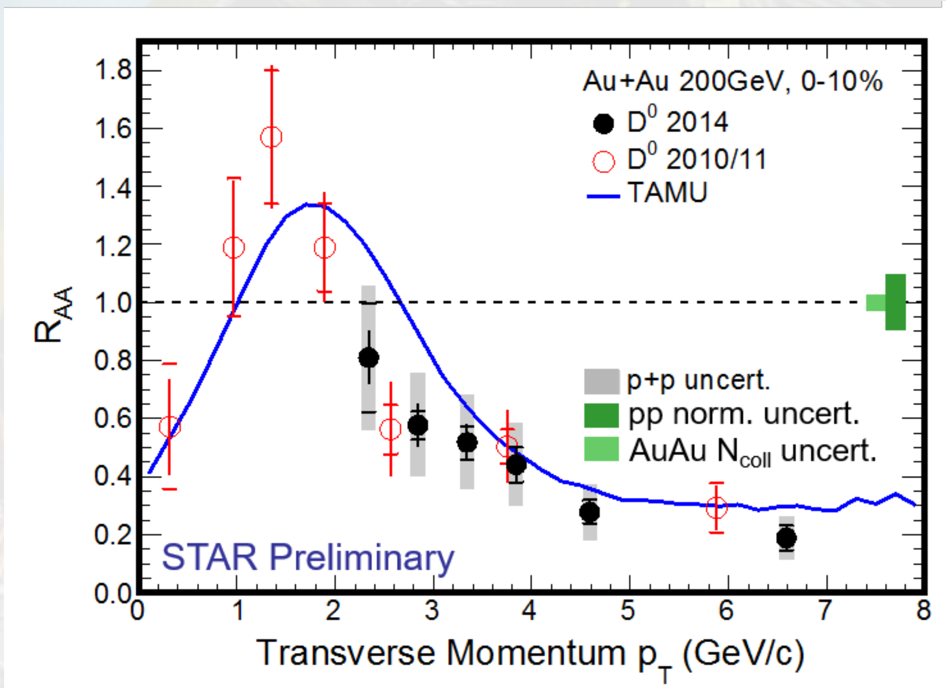


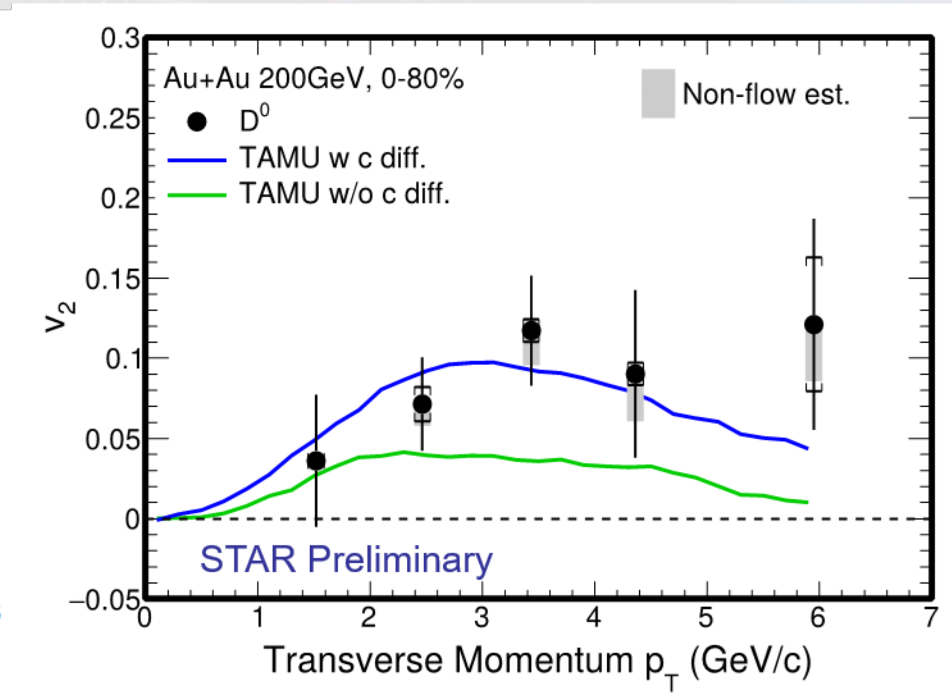
Centrality dependence of charm hadron v_2

First Λ_c measurement in HI collisions
- coalescence hadronization

B->J/ψ with displaced vertex at RHIC
- bottom quark energy loss

Does Charm Flow?





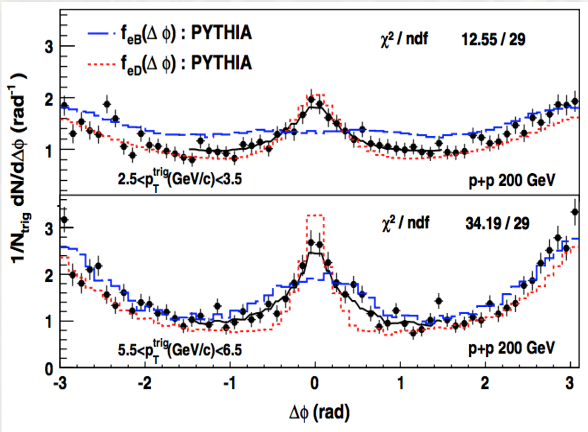
TAMU model: non-perturbative transport + Langevin simulation

- "bump" structure in R_{AA} at low->intermediate p_T
  – coalescence of flowing charm + light quarks
- D-meson v_2 data favor charm quark diffusion / flow in the medium

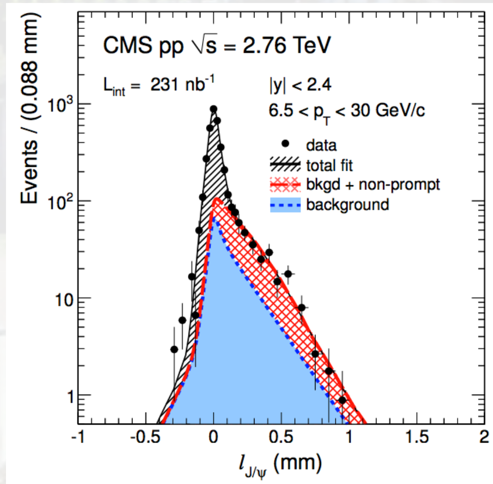
Measuring Bottom

Lower production rate! Lower branching ratios for exclusive reconstruction!

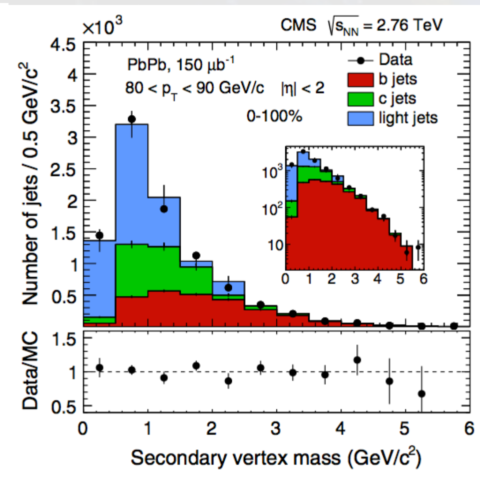
STAR e-h in p+p



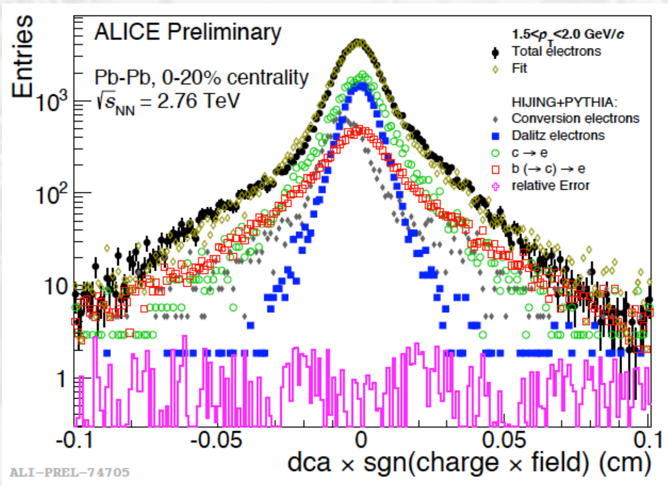
CMS displaced J/ψ



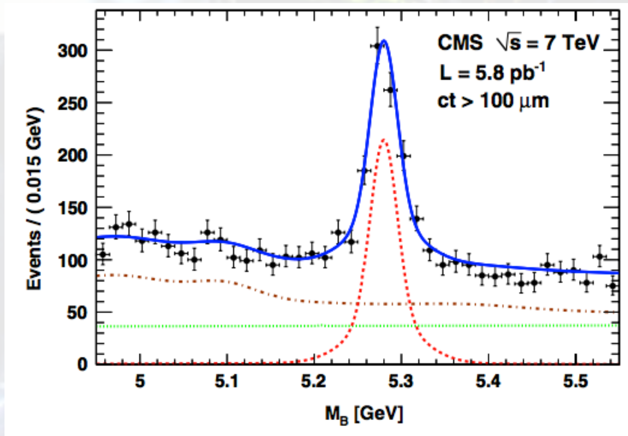
CMS b-jet



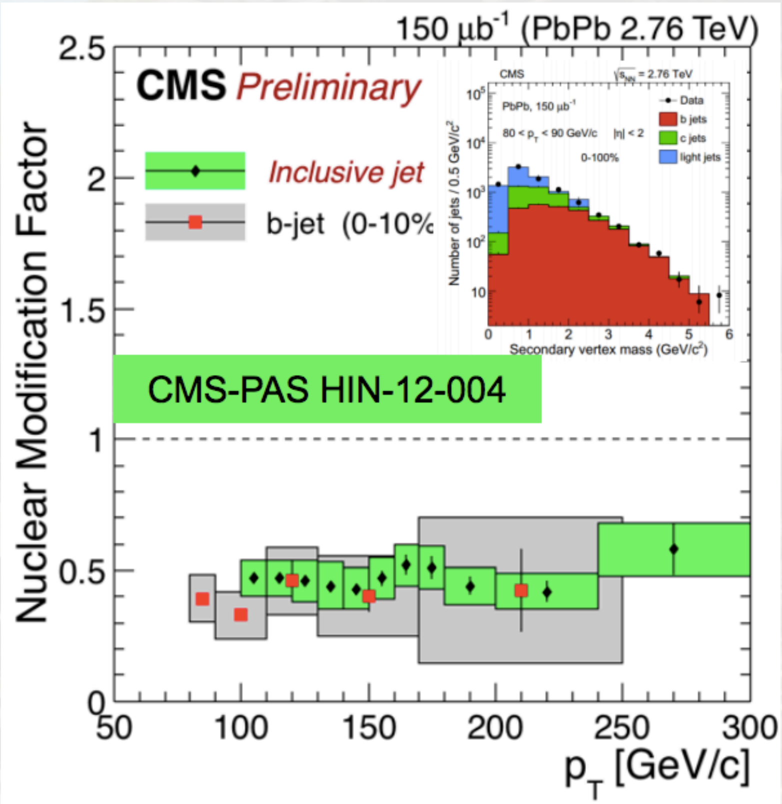
ALICE impact par. of e in Pb+Pb

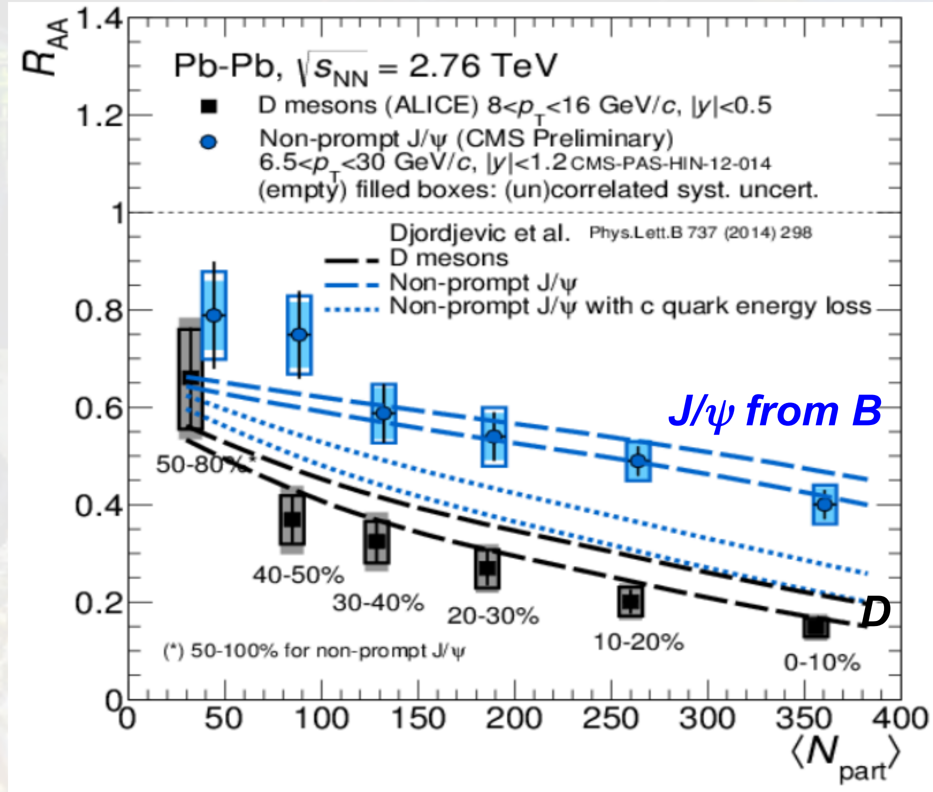


CMS B-meson in p+Pb



Bottom Suppression in Heavy Ion Collisions





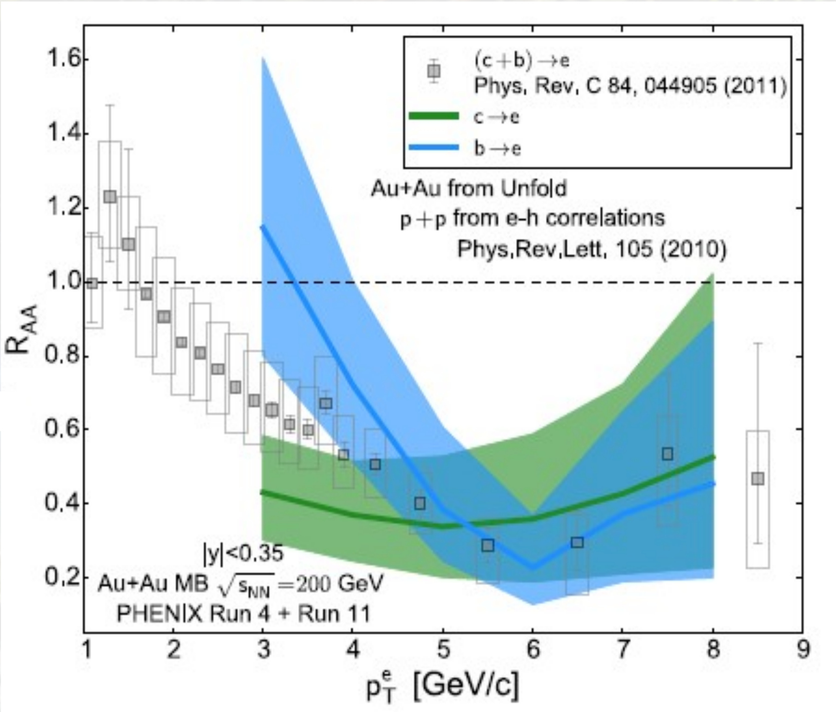
ALICE JHEP 09 (2012) 112, CMS-PAS-HIN-12-014, ALICE arXiv: 1506.06604

R_{AA} of b-jets at p_T>80 GeV/c comparable to that of light jets
caveat: sizable gluon splitting contribution

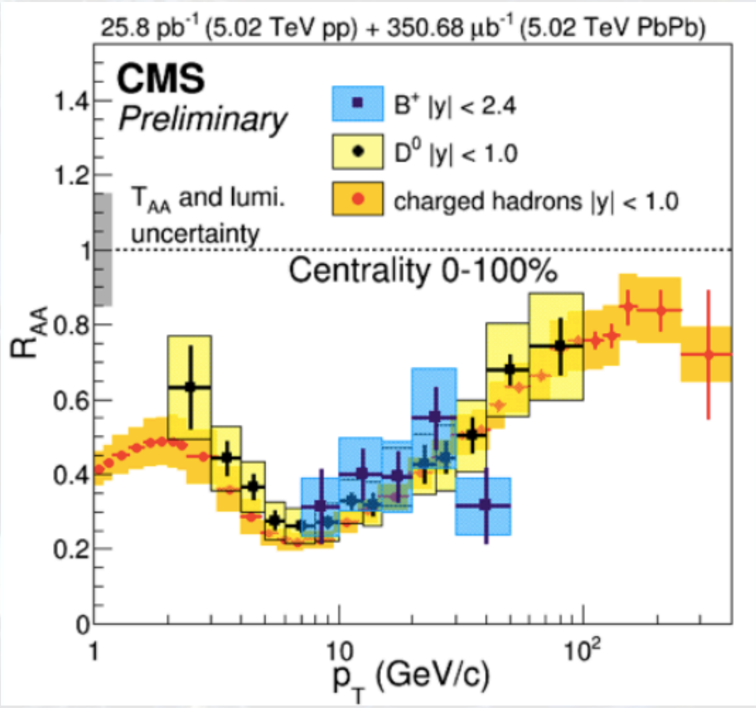
Suppression hierarchy between $R_{AA}(J/\psi^B)$ and $R_{AA}(D)$ at LHC
– consistent with pQCD calculations

Current Bottom Measurements

RHIC

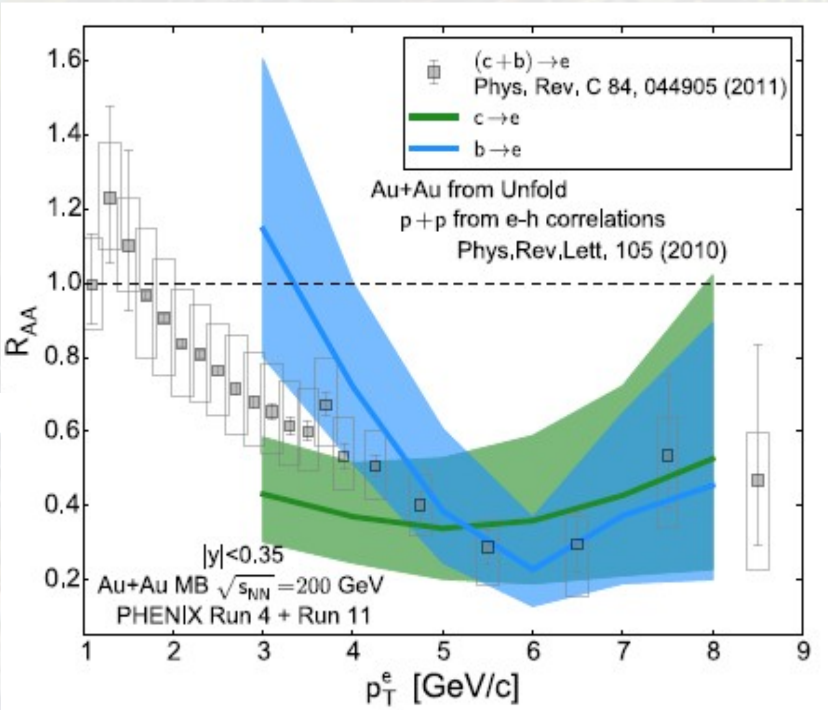


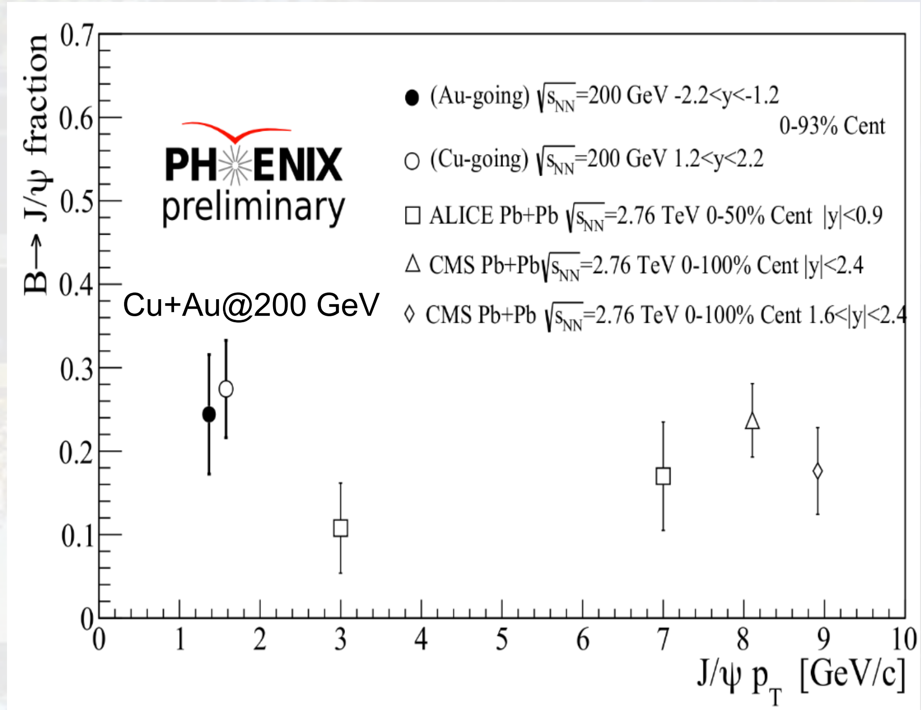
LHC



Measuring Bottom at RHIC

Separation of c and b contribution to electrons / non-prompt J/ψ using impact parameter method with VTX and FVTX at PHENIX





PHENIX, PRC 93 (2006) 034904

Statistics are challenging, hint of less suppression for bottom quark

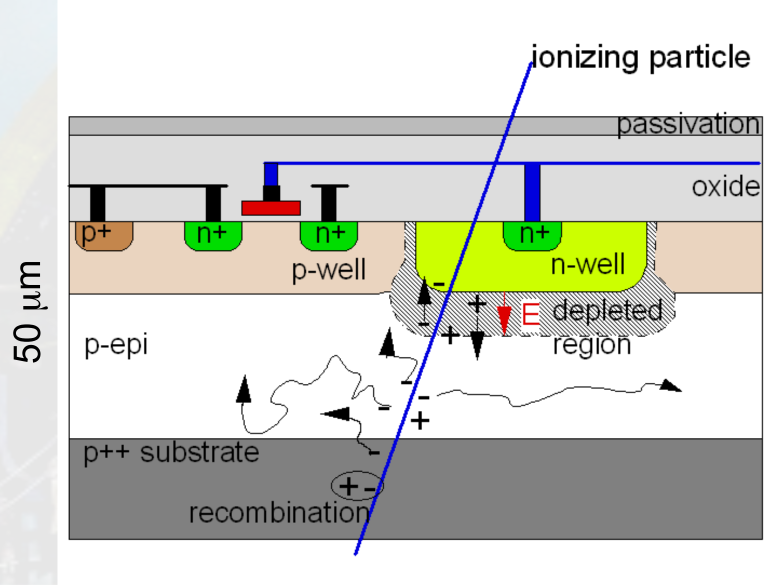
→ High statistics measurement in future heavy flavor program at RHIC

Key Instruments – Pixel Silicon Detector

	ATLAS	CMS	ALICE	PHENIX	STAR
Sensor tech.	Hybrid	Hybrid	Hybrid	Hybrid	**MAPS**
Pitch size (μm^2)	50x400	100x150	50x425	50x425	**20x20**
Radius of first layer (cm)	5.1	4.4	3.9	2.5	2.8
Thickness of first layer	$\sim 1\%X_0$	$\sim 1\%X_0$	$1\%X_0$	$1\%X_0$	**$0.4\%X_0$**

Monolithic Active Pixel Sensors (MAPS)

MAPS pixel cross-section (not to scale)



Properties:

- Standard commercial CMOS technology
- Sensor and signal processing are integrated in the same silicon wafer
- Signal is created in the low-doped epitaxial layer (typically ~10-15 µm) → MIP signal is limited to <1000 electrons
- Charge collection is mainly through thermal diffusion (~100 ns), reflective boundaries at p-well and substrate

MAPS and competition	MAPS	Hybrid Pixel	CCD
Granularity	+	-	+
Small material budget	+	-	+
Readout speed	+	++	-
Radiation tolerance	+	++	-

MAPS - particularly chosen for measuring HF hadron decays in heavy ion collisions

Physics Channels

Hadron	Abundance	cτ (μm)
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

$B \to J/\psi + X$ 1.2%

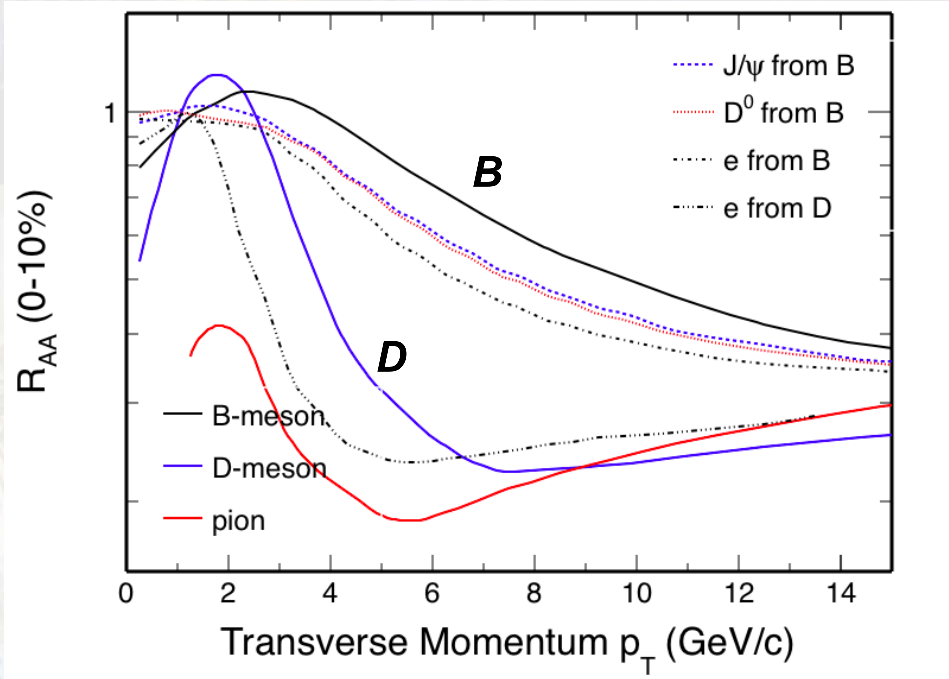
$B \to \overline{D}^0 + X$ 60%

$B \to e + X$ 11%

$B^+ \to \overline{D}^0 \pi^+$ 0.5%

Needed for p_T<10 GeV

b-tagged jet



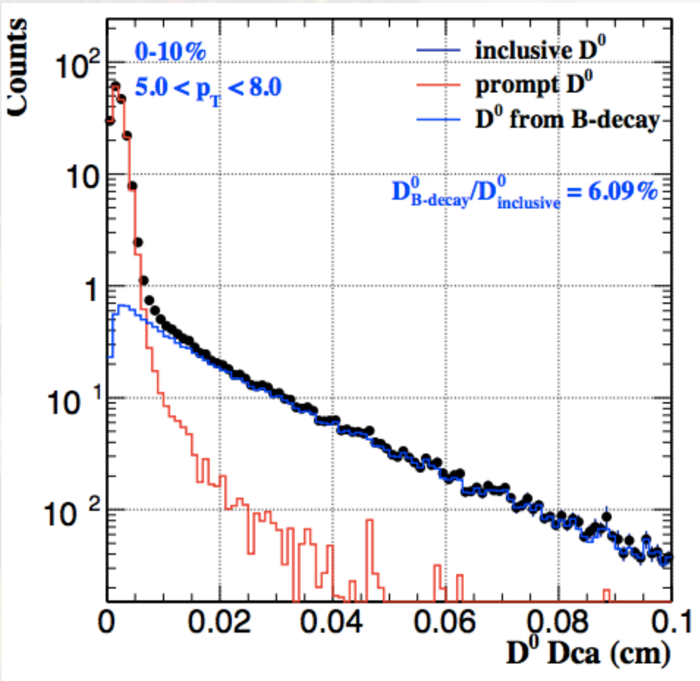
Theory curves on B/D-mesons from TAMU/DUKE/CUJET

Estimation for Non-prompt D^0 Measurements

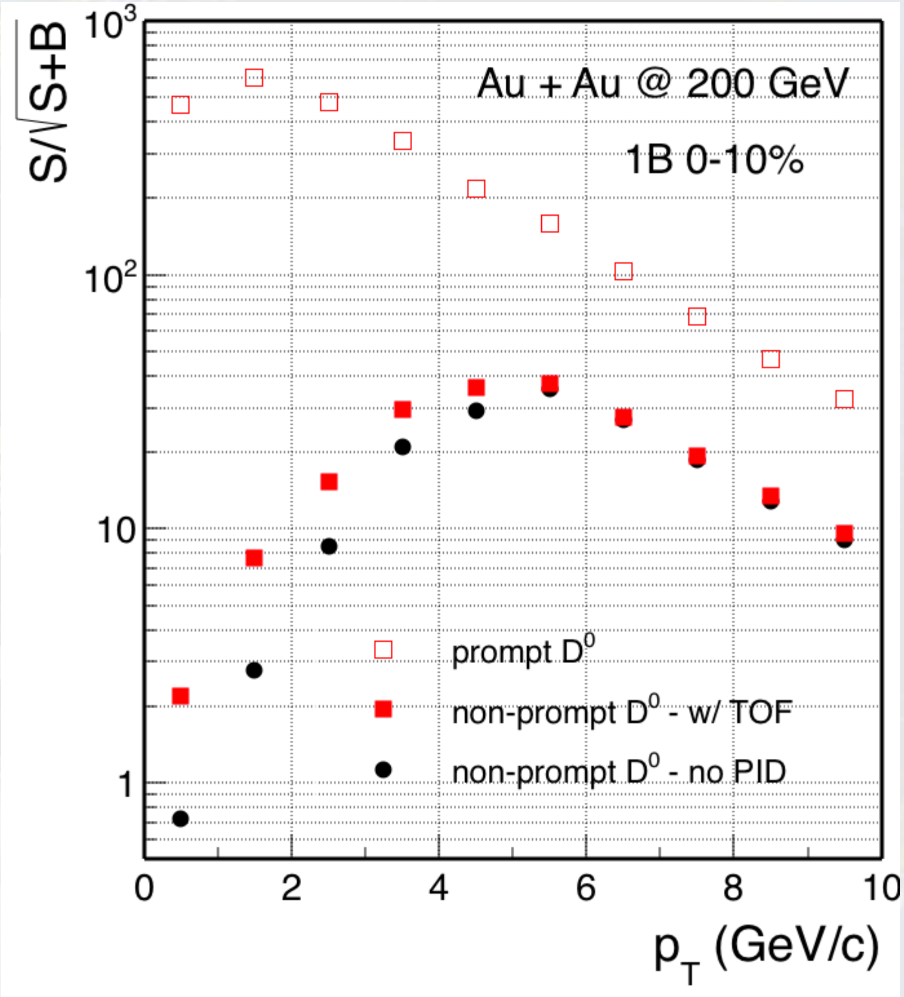
Full signal and background simulation based on data-driven simulation package
- validated with full GEANT simulation

for the TPC+HFT tracking at STAR

Simu. for STAR HFT



D^0 significance in 1B 0-10% Au+Au events



D^0 cross section - STAR measurement
Bottom cross section – FONLLN_{bin}*

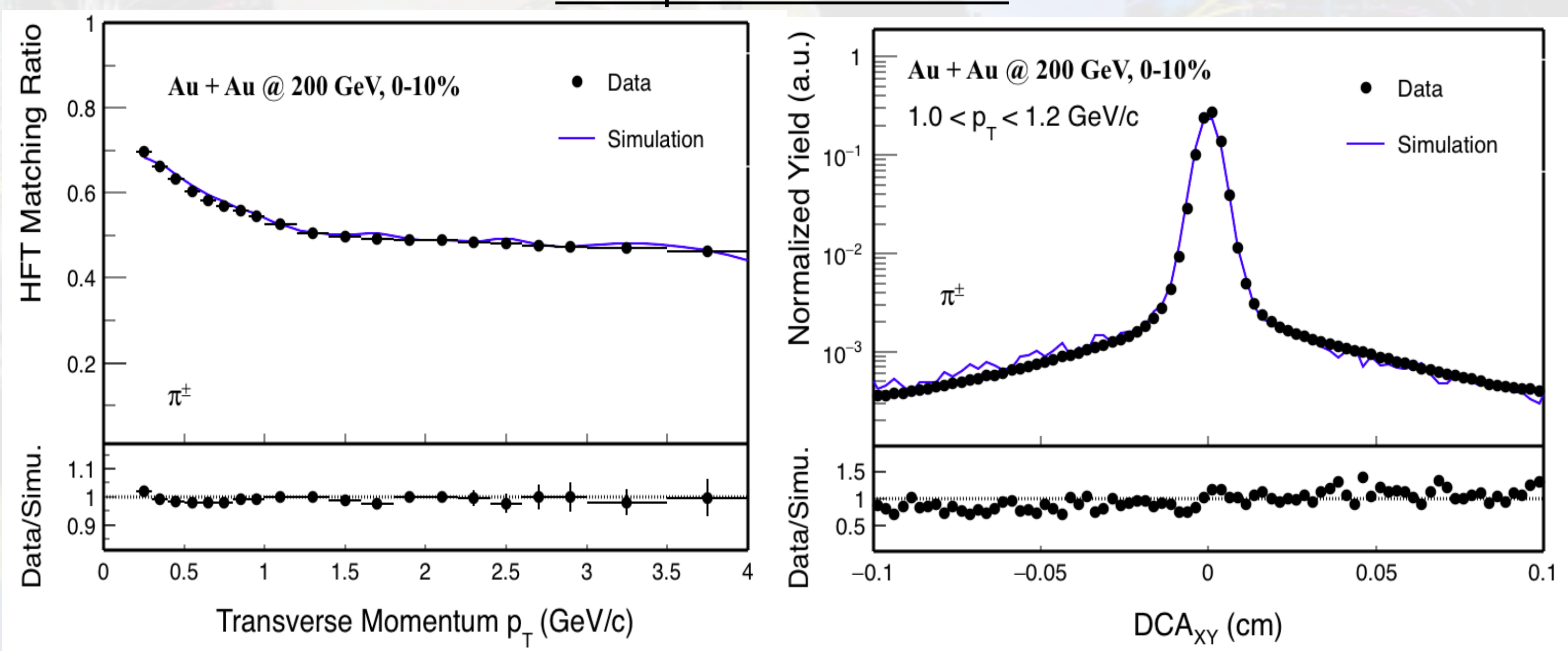
A Bit Detail on the Simulation

• Full GEANT simulation often limited by the background statistics

• Alternative approach: Data-driven fast simulation
- tracking efficiency characterized by a matching ratio between silicon detectors and the TPC
- full DCA distributions represent the tracking performance (including good and mis-matches) – 2D (DCA_xy vs. DCA_z)

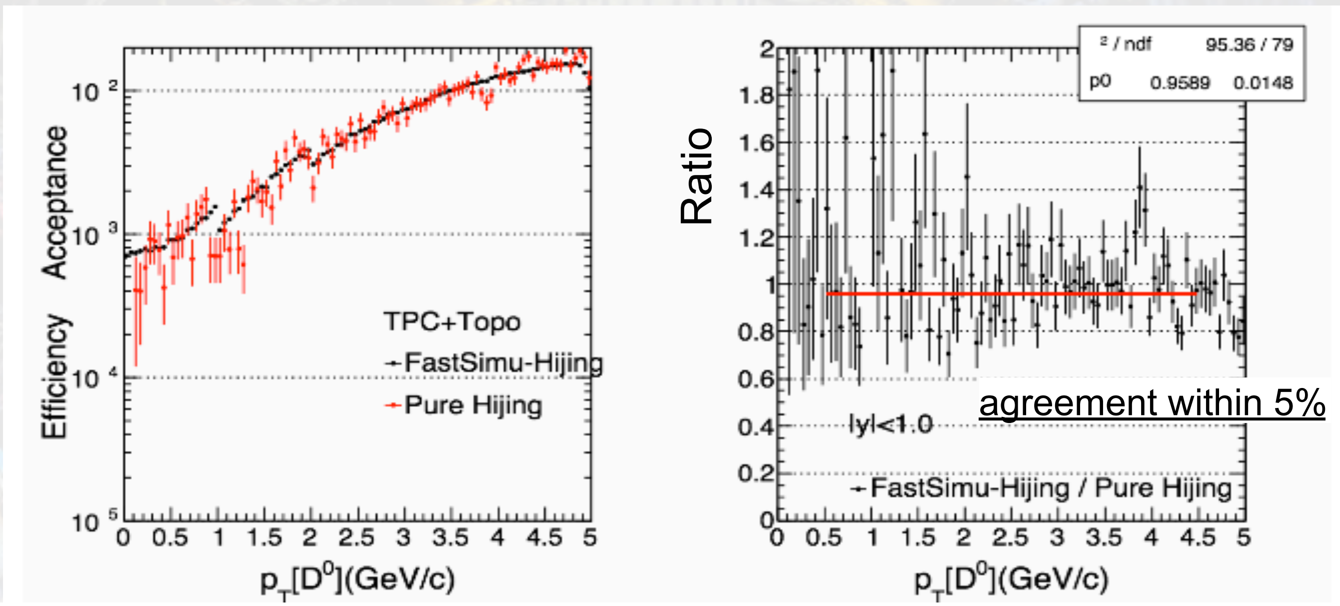
Goal: to capture full distributions (after topological cuts) for both signals and backgrounds

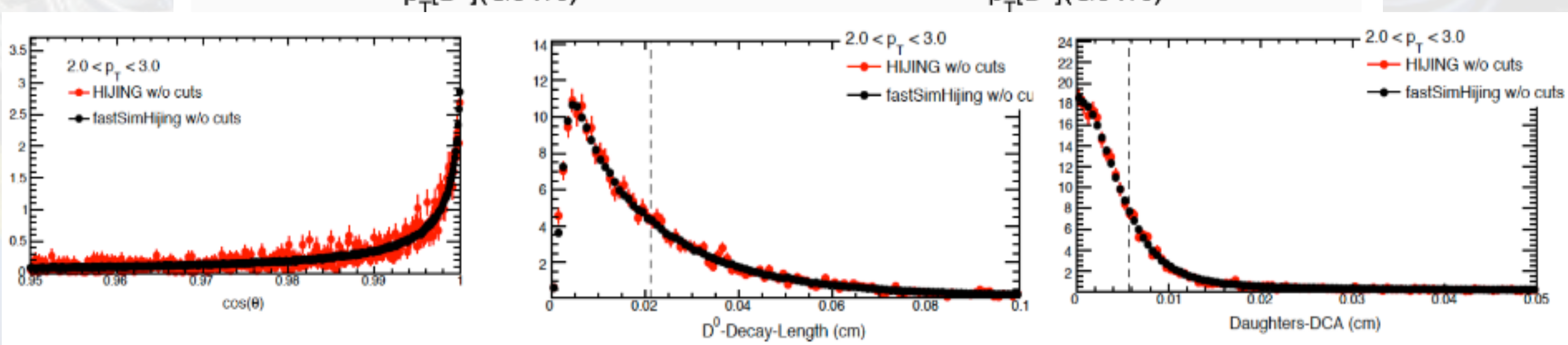
Examples for STAR HFT



Validation with Full GEANT Simulation

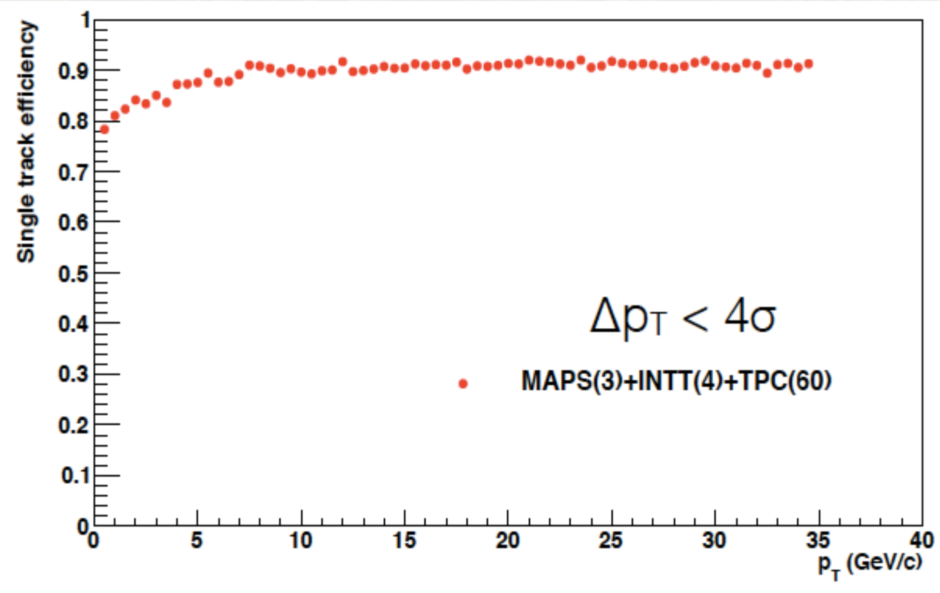
- Hijing+D^0 sample through GEANT + reconstruction
- Data-driven fast simu – inputs taken from Hijing single track performance
- Then compare the efficiencies between fast simu vs. that from Hijing+GEANT directly

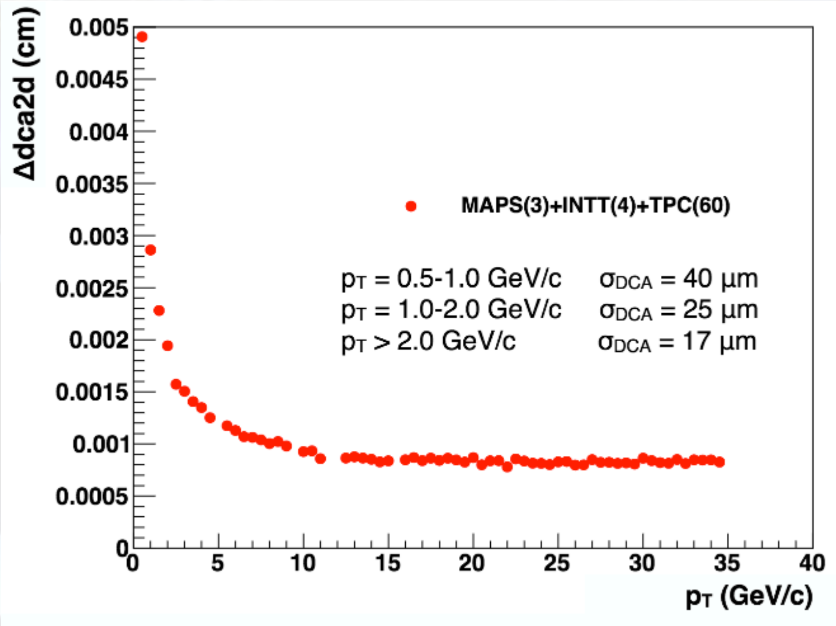




Tracking Performance Input for This Simulation

Input distributions coming from sPHENIX full GEANT simulation performance for single track with TPC+INTT+MAPS





T. Frawley, sPHENIX tracking review, Sept. 2016

A few assumptions - to be verified / fine-tuned with full GEANT simulation

- Low p_T efficiency drop due to fake matches
- Same/comparable resolution in DCA_z dimension, and the correlation between DCA_xy and DCA_z taken from STAR HFT
- The broader DCA structure (due to fake matches) taken from STAR TPC+HFT (conservative)